Physics 20

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Module 3
EFFECTS OF FORCE ON VELOCITY

Rocky View School Division
Red Deer Catholic Regional Schools
Edmonton Public Schools
Pembina Hills Regional School Division
Black Gold Regional Schools
Peace Wapiti School Division No. 76
Calgary Board of Education
Alberta Education

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- Black Gold Regional Schools
- Calgary Board of Education
- Edmonton School District No. 7
- Peace Wapiti School Division No. 76
- Pembina Hills Regional Division No. 7
- Red Deer Catholic Regional Division
- Rocky View School Division No. 41

Physics 20
Module 3: Effects of Force on Velocity
Student Module Booklet
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Students	✓
Teachers	✓
Administrators	
Home Instructors	
General Public	
Other	

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- Alberta Education, **http://www.education.gov.ab.ca**
- Learning Resources Centre, **http://www.lrc.education.gov.ab.ca**
- Tools4Teachers, **http://www.tools4teachers.ca**

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Contents

Physics 20

Unit B Dynamics

Unit B Introduction

Unit B is about 25% of the Physics 20 course. This is equivalent to approximately 20 80-minute classes. You may have to do additional "homework" hours to complete this unit.

In Unit B you will investigate the causes of changes in the velocity of objects and systems. In effect, you will study dynamics and gravitation. You will be introduced to the concepts of gravitational fields to explain gravitational effects. This unit will prepare you for further study of Newton's laws and periodic motion and electric and magnetic fields.

In Module 3 you will look at non-zero (unbalanced) net force and their effect on velocity. You will examine Newton's first law of motion to help you understand the forces acting on an object at rest and an object with uniform motion. Newton's second law of motion will help explain the relationships among net force, mass, and acceleration. You will apply Newton's third law of motion to interactions between two objects. You will examine the differences between static and kinetic forces of friction. You will apply vector tools from Unit A to calculate the resultant force acting on an object, and you will apply Newton's laws of motion to solve linear-motion problems in horizontal, vertical, and inclined planes near the surface of Earth.

In Module 4 you will see that the gravitational force is one of the fundamental forces in nature. You will examine the principles of the Cavendish experiment and study Newton's law of universal gravitation. You will relate the gravitational constant to the local value of the acceleration due to gravity. You will predict differences in weights of objects on different planets.

By the end of this unit, you will be able to explain the effects of balanced and unbalanced forces on velocity and explain that gravitational effects extend throughout the universe.

Think about the following questions as you complete this unit:

- How does the understanding of forces help humans to improve or change their environment?
- How do the principles of dynamics influence the development of new mechanical technologies?
- What role do gravitational effects play in the universe?

Unit B Assessment

Once you have completed this unit, you will have a Unit B Assessment to complete. The Unit B Assessment is a diploma-examination type of question. It will require you to use the entire set of tools that are introduced and worked with in this unit.

Concept Organizer

Unit B – Dynamics

Module 3: Effects of Force on Velocity
- Lesson 1 – Newton's First and Second Laws of Motion
- Lesson 2 – Newton's Third Law
- Lesson 3 – Normal Force and Friction
- Lesson 4 – Free-Body Diagrams and Net Force
- Lesson 5 – Solving Net Force Problems

Module 4: Gravitational Force
- Lesson 1 – Acceleration Due to Gravity
- Lesson 2 – Newton's Law of Universal Gravitation
- Lesson 3 – Universal Gravitational Field Theory and the Density of Earth

Module Descriptions

Module 3: Effects of Force on Velocity

In Module 3 you will study Newton's laws of motion. You will see how these laws let you solve problems relating to forces and moving objects.

Module 4: Gravitational Force

In Module 4 you will study gravitational forces and Newton's law of universal gravitation. You will explore the implications of the law of universal gravitation and learn to find the weights of objects on different planets.

Effects of Force on Velocity

Module Introduction

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Isaac Newton is one of the major figures in the history of dynamics. You'll see his name throughout this module. In fact, most of the work you'll complete revolves around Newton's laws of motion.

- **Newton's first law: law of inertia**: A body continues in its state of rest or of motion in a straight line with a constant speed unless an external, unbalanced force acts on it.
- **Newton's second law:** $\vec{F} = m\vec{a}$: The rate of change of velocity of an object is proportional to and in the same direction as the unbalanced force acting on it.
- **Newton's Third Law:** $\vec{F}_{\text{action}} = -\vec{F}_{\text{reaction}}$: For every action force, there exists a reaction force that is equal in magnitude but opposite in direction.

As you work in this module, keep the following questions in your mind:

- How is the motion of an object affected by forces applied to it?
- How do unbalanced forces affect the motion of an object?
- How do Newton's laws help explain why motion occurs?
- How do you find a reaction force?
- How does friction affect moving objects?
- How does friction affect making an object move?
- How do free-body diagrams, vector analysis, and Newton's second law help solve moving-object problems?

Big Picture

It's Saturday morning, and you are waiting for a ride to the new park. Last week, you volunteered to help put together playground equipment bought by a local service club. Once you and the rest of the volunteers get there, the park will be a beehive of activity for a few hours.

While you are waiting for your ride, you begin to think about the people you'll be working with today and all of the stuff that needs to be put together. Just getting everything and everyone in the same place at the right time is a logistical wonder.


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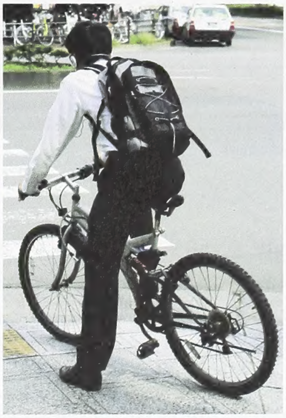
How will all the people get to the park? Will they walk, cycle, or take a city bus? What about the sand for the playground and the pieces of playground equipment? How will all of it get to the park at just the right time?



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You can easily imagine a big dump truck hauling in the sand and a delivery truck or van dropping off the playground pieces, but how did the fasteners stamped "Mexico" or the boxes with "Made in Taiwan" written on them get here?

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If you thought about it, you could use the language and tools from Unit A to write a description of all the movement involved in getting ready for building the playground. From your studies in Unit A, you would be able to draw a vector to describe the motion of each of the modes of transportation, but that wouldn't explain why things move or how their motion can be controlled.

You are about to study the causes of motion. You will be looking at what makes things move the way they do. In short, it's all about forces.

In Unit B you will study dynamics—how forces affect the motion of objects. You'll be able to explain why the sand slides out of a tilting dump truck instead of just staying put.

In the first module of Unit B, Effects of Force on Velocity, you will use your knowledge about vectors from Unit A to solve problems in dynamics.

This includes

- adding vectors graphically and algebraically
- breaking vectors into x and y components
- finding angles from x and y components

If you need to review vectors, read pages 68 to 89 in your textbook.

As you work through this module, keep the following questions in mind:

- How is the motion of an object affected by forces applied to it?
- How do unbalanced forces affect the motion of an object?
- How do Newton's laws help explain why motion occurs?
- How do you find a reaction force?
- How does friction affect moving objects?
- How does friction affect making an object move?
- How do free-body diagrams, vector analysis, and Newton's second law of motion help solve moving-object problems?

In This Module

Lesson 1—Newton's First and Second Laws of Motion

In this lesson you will explore and apply Newton's first and second laws of motion as they relate to unbalanced forces and changes in velocity.

You will explore the following questions:

- How is the motion of an object affected by forces applied to it?
- How do unbalanced forces affect the motion of an object?
- How do Newton's laws help explain why motion occurs?

Lesson 2—Newton's Third Law

In this lesson you will explore the implications of Newton's third law.

You will focus on the following essential questions:

- How do Newton's laws help explain why motion occurs?
- How do you find a reaction force?
- How does friction affect moving objects?

Lesson 3—Normal Force and Friction

In this lesson you will see a brief introduction to free-body diagrams and explore the nature of the normal force and its relationship to weight. You will also graphically determine an expression for kinetic friction and calculate kinetic, static, and rolling friction in a variety of situations.

You will explore the following questions in this lesson:
- How does friction affect moving objects?
- How does friction affect making an object move?
- How do free-body diagrams, vector analyses, and Newton's second law help solve moving-object problems?

Lesson 4—Free-Body Diagrams and Net Force

In this lesson you will construct labelled free-body diagrams for objects in a variety of physical situations. You will use these diagrams to derive net force equations that describe the observed acceleration of objects.

You will explore the following questions:
- How is the motion of an object affected by the forces applied to it?
- How do unbalanced forces affect the motion of an object?
- How do free-body diagrams, vector analyses, and Newton's second law help solve moving-object problems?

Lesson 5—Solving Net Force Problems

In this lesson and the associated labs you will learn to apply Newton's second law and free-body diagram analysis to solve linear (one-dimensional) and non-linear (two-dimensional) net force problems.

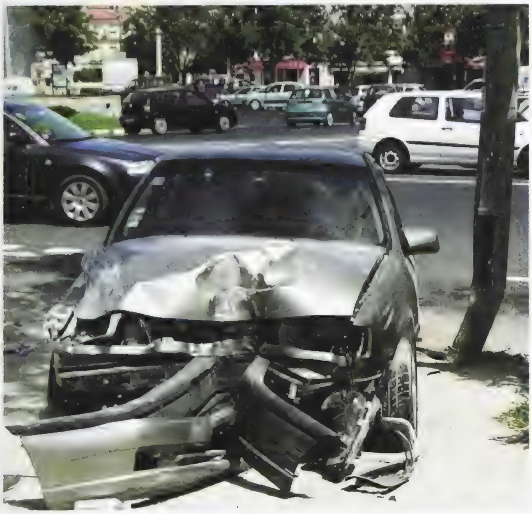
You will explore the following question:
- How do free-body diagrams, vector analyses, and Newton's second law help solve moving-object problems?

Module 3 Assessment

The assessment for Module 3 consists of five (5) assignments:
- Module 3: Lesson 1 Assignment
- Module 3: Lesson 2 Assignment
- Module 3: Lesson 3 Assignment
- Module 3: Lesson 4 Assignment
- Module 3: Lesson 5 Assignment

Lesson 1—Newton's First and Second Laws of Motion

Get Focused



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Getting around can sometimes cause unwanted consequences. Transport Canada statistics from the year 2000 show that there were 158 499 car accidents across Canada leading to 2926 fatalities and 227 403 injuries. The injuries and fatalities that year likely impacted more than one-million people in a variety of ways. Chances are fairly good that you, too, will be or have already been impacted by a transportation-related accident. Naturally, this leads us to consider ways to improve transportation safety.

force: a push or a pull, the cause of any change in the motion of an object

unbalanced force: a net push or pull in one direction

How can new and innovative technologies be applied to vehicle and transportation infrastructure to reduce the frequency of accidents causing injury and death on Canada's roadways? To answer this, you first need to understand the relationship between **force** and velocity. Sir Isaac Newton developed a number of laws of motion about these relationships. Newton's first and second laws of motion, which relate to **unbalanced forces** and changes in velocity, will help you begin to answer questions about technology being used to reduce the severity of traffic accidents.

As you work through this lesson, keep the following questions in mind:
- How is the motion of an object affected by forces applied to it?
- How do unbalanced forces affect the motion of an object?
- How do Newton's laws help explain why motion occurs?

Module 3: Lesson 1 Assignments

In this lesson you will complete the Lesson 1 Assignment in the Module 3 Assignment Booklet.
- Lab—LAB 1, LAB 2, LAB 3, LAB 4, LAB 5, and LAB 6
- Try This—TR 3, TR 4, TR 5, and TR 6

The other questions in this lesson are not marked by the teacher; however, you should still answer these questions. The Self-Check and Try This questions are placed in this lesson to help you review important information and build key concepts that may be applied in future lessons.

After a discussion with your teacher, you must decide what to do with the questions that are not part of your assignment. For example, you may decide to submit to your teacher the responses to Try This questions that are not marked. You should record the answers to all the questions in this lesson and place those answers in your course folder.

Watch and Listen

Go to your Physics 20 Multimedia DVD, and watch the video called "Newton's Laws Part 2" that explains Newton's first and second laws.

Explore

Newton's laws of motion are physical laws that describe the relationship between the force acting on a body and the motion of the body. All three laws were first published in Latin in Newton's book titled *Philosophiae Naturalis Principia Mathematica* (1687). Together, his three laws form the backbone of classical mechanics, which is the branch of physics concerned with explaining the behaviour of physical bodies as they are subjected to forces. You will explore Newton's first and second laws in the following activities.

Newton's First Law: Law of Inertia

Lex I: Corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directum, nisi quatenus a viribus impressis cogitur statum illum mutar.

The modern translation of the first law is as follows:

A body continues in its state of rest or of motion in a straight line with a constant speed unless an external, unbalanced force acts on it.

This law is also referred to as the law of inertia. **Inertia** refers to an object's ability to resist changes in its velocity. All objects resist changes in their motion, which is why an unbalanced force must be applied in order to change an object's velocity. Inertia is related to the object's mass: a heavier object will resist changes in its velocity to a greater extent than a similar object of less mass. Therefore, a more massive object has a greater amount of inertia.

inertia: a property of matter that causes matter to resist changes in speed or direction

Newton's first law implies the following:

- An object that is at rest will stay at rest until an unbalanced force acts upon it, giving it motion.
- An object that is in motion will not change velocity until an unbalanced force acts upon it.

The first point seems obvious. The second point, however, is not as easily understood since an object rarely maintains a constant velocity for an extended period. The world is far too full of unbalanced forces to observe constant velocity in the real sense.

Read

Read pages 137 to 139 of your textbook to see examples of Newton's first law and inertia.

Self-Check

SC 1. What do you call the tendency of objects to resist any change in their velocity?

SC 2. Why do objects in motion usually come to rest despite their inertia?

Check your work with the answer in the appendix.

Try This

TR 1. Complete "3-3 QuickLab: Challenges with Inertia" on page 138 of your textbook; then answer question 1.

TR 2. Go to page 142 of your textbook and answer question 4 of "3.2 Check and Reflect."

Newton's first law says, in essence, that the velocity of an object remains constant (either at zero or a steady non-zero value) unless acted on by an outside unbalanced force. What happens if it *is* acted on by an outside unbalanced force? Complete the following lab to find out.

Module 3: Lesson 1 Assignment

Remember to submit the answers to LAB 1, LAB 2, and LAB 3 to your teacher as part of your Lesson 1 Assignment in your Module 3 Assignment Booklet.

Lesson 1 Lab: Relating Acceleration and Net Force

With the approval and supervision of your teacher, go to pages 144 and 145 of your textbook and complete "3-5 Inquiry Lab: Relating Acceleration and Net Force." This lab is best done in groups of three or four students, if possible.

LAB 1. Write a hypothesis. Follow the directions under the subheading "Hypothesis" on page 144 of your textbook.

LAB 2. Complete all the steps of "Procedure." Then answer questions 1, 2, 3, 4, and 5 of the "Analysis." You will create copies of "Table 3.2" and "Table 3.3" on page 145 and submit the tables with your recorded data to your teacher.

LAB 3. Answer questions 7, 8, 9, and 10 of "Analysis" on page 145 of your textbook.

In "3-5 Inquiry Lab," you kept the total mass constant (controlled variable) and changed the net force (manipulated variable). What would happen if you kept net force constant and manipulated the total mass? Complete the lab titled "Relating Acceleration and Mass" to find out.

Module 3: Lesson 1 Assignment

Remember to submit the answers to LAB 4, LAB 5, and LAB 6 to your teacher as part of your Lesson 1 Assignment in your Module 3 Assignment Booklet.

Lesson 1 Lab: Relating Acceleration and Mass

With a group of three or four students, if possible, and the approval of your teacher, complete "3-6 Design a Lab: Relating Acceleration and Mass" on page 147 of your textbook.

The following questions are based on the directions in the section titled "Design and Conduct Your Investigation." You will need to complete the third bullet before continuing with LAB 5 and LAB 6.

LAB 4. Complete the step outlined in the first bullet, and write a hypothesis. Use the words *if* and *then*.

LAB 5. Complete the steps outlined in the third bullet. You will create two graphs.

LAB 6. Complete the steps outlined in the fourth bullet. You will analyze the data and compare it to your hypothesis.

Keep a copy of your written responses to "Design and Conduct Your Investigation" in your Physics 20 course folder. As well, remember to submit your finished work to your teacher.

Read

Read pages 146 to 148 in your textbook starting at "Relating Acceleration and Net Force." Look for the way acceleration is related to force and to mass, and read about what *inertial mass* means.

Self-Check

SC 3. The same net force is applied to two objects, A and B. If object B has three times the mass of object A, what can you say about the acceleration of object B compared to object A?

Check your work with the answer in the appendix.

Newton's Second Law

Lex II: Mutationem motus proportionalem esse vi motrici impressae, et fieri secundum lineam rectam qua vis illa imprimitur.

The modern translation of the second law is as follows:

The rate of change of velocity of an object is proportional to and in the same direction as the unbalanced force acting on it.

Recall that kinematics describes the motion of an object in terms of its velocity, displacement, and acceleration. Now consider that dynamics explains the motion of an object in terms of the force causing it. The basic equation that allows motion to be explained is contained in the second law: If an unbalanced force is applied to an object, the object will accelerate in the direction of the unbalanced force.

The word *unbalanced* can be replaced by the word *net*, as you will notice in the following examples:

- The magnitude and direction of acceleration is directly proportional to the magnitude and direction of the net (unbalanced) force causing it.

- The magnitude of the acceleration is inversely proportional to the mass of the object. For example, if the same net (unbalanced) force acts on two objects, one being half as massive as the other, the acceleration of the less massive object will be larger.

Newton's second law relates the change in velocity of an object with the unbalanced force causing it.

The equation is as follows:

$\vec{F} = m\vec{a}$

<table>
<tr><th>Quantity</th><th>Symbol</th><th>SI Unit</th></tr>
<tr><td>net force</td><td>$\vec{F}_{net}$</td><td>N</td></tr>
<tr><td>acceleration</td><td>$\vec{a}$</td><td>m/s^2</td></tr>
<tr><td>mass</td><td>m</td><td>kg</td></tr>
<tr><td colspan="3">* 1 N is equivalent to 1 $kg{\cdot}m/s^2$. In other words, 1 N of force will cause a 1-kg object to accelerate at 1 m/s^2.

** $F = ma$ is a common convention that describes Newton's second law, but it is actually a combination of the first and third laws, presented in a useful form. This form did not begin to be used until the eighteenth century, after Newton had died; however, it is clearly implied in his laws.</td></tr>
</table>

Problem Solving with Newton's Second Law

net force: the sum of the forces acting on an object (see *unbalanced force*)

Newton's second law can be used to predict the acceleration of an object. In the simplest case, a single force acts on an object, causing it to accelerate. In a more complex case, the vector sum of many forces (net force) acts on an object, causing it to accelerate. In all cases, however, the observed acceleration of the object will be in the same direction as the **net force** (the vector sum of all the forces acting on the object).

The following three example problems show how the calculations are to be done.

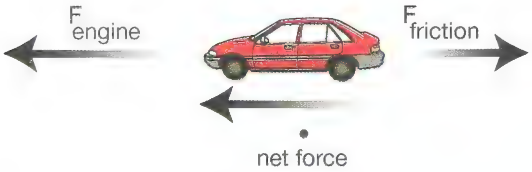
Example Problem 1

A car being driven on a road experiences several forces—the force of friction due to the road and the air, and the force of the engine that pushes the car forward. Describe the car's acceleration in the following situations:

a. The engine force is greater than the frictional force.
b. The engine force is less than the frictional force.
c. The engine force equals the frictional force.

Solution

a. $\vec{F}_{engine} > \vec{F}_{friction}$ There is a net force that will cause the car to accelerate forward (speed up).



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b. $\vec{F}_{engine} > \vec{F}_{friction}$ There is a net force that will cause the car to accelerate backwards (slow down).

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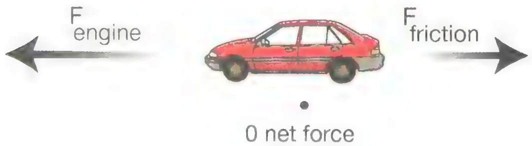
c. $\vec{F}_{engine} > \vec{F}_{friction}$ The net force is zero. According to Newton's first law, the car will maintain a constant velocity.



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Example Problem 2

What force is required to accelerate a 60.0-kg mass at –4.00 m/s^2?

Given

$m = 60.0$ kg $\quad \vec{a} = -4.00$ m/s2

Required

the net force ($\vec{F}_{\text{net}}$)

Analysis and Solution

Use Newton's second law to find the net force.

$$\begin{aligned}\vec{F}_{\text{net}} &= m\vec{a} \\ &= (60\text{ kg})\left(-4.00\text{ m/s}^2\right) \\ &= -240\text{ N}\end{aligned}$$

Paraphrase

The required force is –240 N.

Example Problem 3

A 4.00-kg mass resting on a frictionless surface experiences a 16.0-N force acting west. What is the resulting acceleration?

Given

$m = 4.00$ kg $\vec{F}_{\text{net}} = 16.0$ N [W]

Required

the acceleration of the mass ($\vec{a}$)

Analysis and Solution

Use the scalar form of Newton's second law to find the acceleration, because the acceleration will be in the same direction as the force.

$$
\begin{aligned}
F_{\text{net}} &= ma \\
a &= \frac{F}{m} \\
&= \frac{16.0 \text{ N}}{4.00 \text{ kg}} \\
&= 4.00 \text{ m/s}^2 \\
\vec{a} &= 4.00 \text{ m/s}^2 \ [\text{W}]
\end{aligned}
$$

Paraphrase

Correct to 3 significant digits, the resulting acceleration is 4.00 m/s^2 [W].

Module 3: Lesson 1 Assignment

Remember to submit the answers to TR 3, TR 4, TR 5, and TR 6 to your teacher as part of your Lesson 1 Assignment in your Module 3 Assignment Booklet.

Try This

In solving the following problems, be sure to write the equation, rearrange the equation (if necessary), and substitute values for the variables in the equation. Then solve and answer the question.

TR 3. If a vehicle is involved in a collision that produces a −1500 N net force, what is the acceleration of a 75.5-kg passenger in the car?

TR 4. If an unbalanced force of +55.2 N causes a hockey puck to accelerate across some ice with an acceleration of $+100 \text{ m/s}^2$, what is the puck's mass?

TR 5. A plane with a mass of 4.50×10^3 kg accelerates on takeoff at 10.0 m/s^2. What is the net force acting on the plane?

TR 6. A car can accelerate at 18.0 m/s^2 and has a mass of 3500 kg. A motorcycle engine can produce 9000 N of force at maximum power output. If the motorcycle has a mass of 565 kg, can it accelerate faster than the car?

Reflect and Connect

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How can new and innovative technologies be applied to vehicle and transportation infrastructure in order to reduce injury and death on Canada's roadways?

Safety devices, such as airbags and seat belts, are designed to reduce injury and save lives in the event of an accident. In an accident, there are often two collisions. The first collision involves the car colliding with another car or object.

The second collision involves an occupant in the vehicle hitting either the windshield or dashboard, or both.

Try This

TR 7. Read pages 140 and 141 of your textbook. Then begin "3-4 Decision-Making Analysis: The Airbag Debate" on page 141. Complete "Analysis" questions 1 and 2.

TR 8. Answer **either** Part A **or** Part B. You do not have to complete both parts.

Part A: Using Newton's laws, explain why a second collision always follows the first. Record your answer in your Physics 20 course folder.

Part B: Using Newton's laws, explain how an airbag and a seat belt minimize the force and acceleration of the second collision that often causes injury and death. Record your answer in your Physics 20 course folder.

Discuss

In Alberta, red-light cameras may be installed at intersections with high collision rates.

The camera takes a picture of any vehicle that enters the intersection when the light is red. If the picture identifies the vehicle's license plate, a summons or fine is sent to the registered owner.

This "safety" device reduces injury and vehicle damage at controlled intersections, yet its use is controversial. Think of benefits and costs of such a device as you do the following questions.

D 1. Why are intersection-related collisions likely to cause severe injury and death?

D 2. What makes a red-light camera effective at reducing the severity and number of collisions?

D 3. What social and economic implications were considered in deploying such technology?

D 4. What other traffic safety-related applications can this technology be applied to?

Reflect on the Big Picture

Each of the Reflect on the Big Picture sections in this module will ask you to consider the movement of people or goods. Complete one or both of the following activities:

- Prepare a short speech (e.g., one or two minutes) on how Newton's first two laws explain why the people, the vehicle, and the broken parts move as they do when a vehicle hits an immovable object. You can present your speech in written, audio, podcast, or video form.
- Create a drawing, painting, or multimedia presentation involving moving people or goods that summarizes Newton's first two laws.

Store your completed reflection in your Physics 20 course folder.

Module 3: Lesson 1 Assignment

Make sure you have completed all of the questions for the Lesson 1 Assignment. Check with your teacher about whether you should submit your assignment now or wait until all of the Module 3 assignments have been completed.

Lesson Summary

As you worked through this lesson, you should have answered these questions:

- How is the motion of an object affected by forces applied to it?
- How do unbalanced forces affect the motion of an object?
- How do Newton's laws help explain why motion occurs?

Newton's first and second laws of motion relate to unbalanced forces and changes in velocity.

- **Newton's first law: law of inertia**: A body continues in its state of rest or of motion in a straight line with a constant speed unless an external, unbalanced force acts on it.

- **Newton's second law:** The rate of change of velocity of an object is proportional to and in the same direction as the unbalanced force acting on it. The equation is $\vec{F} = m\vec{a}$.

Newton's first and second laws explain the vector motion of an object and can be applied to understand and to solve transportation-related issues.

Lesson Glossary

force: a push or a pull, the cause of any change in the motion of an object

inertia: a property of matter that causes matter to resist changes in speed or direction

net force: the sum of the forces acting on an object (see *unbalanced force*)

unbalanced force: a net push or pull in one direction

Lesson 2—Newton's Third Law

Get Focused

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One of the oldest ways of moving around is walking. Usually it's easy, but ice can quickly change that.

Your first experience with walking on ice likely taught you two things. First, it is very slippery; and second, it is hard—especially for an uncontrolled landing! A question you likely didn't ask while lying on the ice was "why?" Why is the ice so slippery? What does it mean to be slippery?

The answer to these questions is related to **friction**. Friction between your shoes and the ground provides traction to maintain your balance and enables you to move. Since ice is a nearly frictionless surface, you can quickly lose your ability to maintain balance and move while standing on it.

friction: the resistance to motion between two surfaces in contact

Imagine that the ice that the boy in the photo is standing on was "perfectly" frictionless. Would he be able to move or even stand up? Now, imagine that he had a physics textbook with him and had studied Newton's three laws of motion. How could he use the book to get to the shore if no friction was present?

As you work through this lesson, keep these important questions in mind:

- How do Newton's laws help explain why motion occurs?
- How do you find a reaction force?
- How does friction affect moving objects?

Module 3: Lesson 2 Assignments

In this lesson you will complete the Lesson 2 Assignment in the Module 3 Assignment Booklet.

- Lab—LAB 1, LAB 2, LAB 3, and LAB 4
- Try This—TR 2, TR 3, TR 4, TR 5, and TR 6
- Discuss—D 1 and D 2

You must decide what to do with the questions that are not marked by the teacher.

Remember that these questions provide you with the practice and feedback that you need to successfully complete this course. You should respond to all the questions and place those answers in your course folder.

Watch and Listen

Go to your Physics 20 Multimedia DVD, and watch the video called "Newton's Laws Part 3" that introduces you to Newton's third law.

Explore

Newton's Third Law

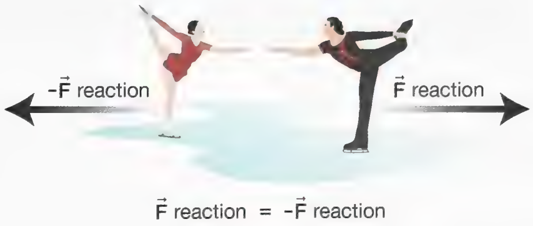
Lex III: Actioni contrariam semper et æqualem esse reactionem: sive corporum duorum actiones in se mutuo semper esse æquales et in partes contrarias dirigi.

The modern translation of this law is that all forces occur in pairs, equal in magnitude and opposite in direction. Expressed as an equation, it is

$$\vec{F}_{\text{action}} = -\vec{F}_{\text{reaction}}$$

Lesson 2 Lab: Newton's Third Law

In simple terms, Newton's third law means that if one object exerts a force on another, the other object simultaneously exerts an equal force back on the first object. For example, if a skater pushes on a smaller skater with $\vec{F}_{\text{action}}$, then the smaller skater pushes back on the larger skater with $\vec{F}_{\text{reaction}}$, which is equal in magnitude but opposite in direction.



The applet used for this lab lets you simulate two skaters pushing away from one another. You can learn more about the simulation and how to use it by reading Show Me found at the top of the simulation screen.

Problem

If one object exerts a force on another, will the other object simultaneously exert an equal force back on the first object?

Go to **www.learnalberta.ca**. You may be required to input a username and password. Contact your teacher for this information. Enter the search terms “Momentum Conservation” in the search bar. Choose the item called “Momentum Conservation (Grades 11 and 12).” Open the simulation that will demonstrate Newton’s third law; then continue with the procedure.

Procedure

- Reset the applet by pressing “Reset” ( ).
- Press the “Data” button ( ) to display information about each skater.
- Press “Play” ( ), and observe the skaters moving apart. Keep the mass of skater 1 at 60.0 kg and the mass of skater 2 at 45.0 kg.

Observations and Analysis

Module 3: Lesson 2 Assignment

Remember to submit the answers to LAB 1, LAB 2, LAB 3, and LAB 4 to your teacher as part of your Lesson 2 Assignment in your Module 3 Assignment Booklet.

LAB 1. Record the information from the following chart, and complete the calculations for skater 2. (The calculations for skater 1 have been done for you as examples.) Let motion to the right be positive and motion to the left be negative.

Skater 1	Skater 2
initial velocity = 0.00 m/s	initial velocity = 0.00 m/s
final velocity = –0.23 m/s	final velocity = ____________
change in velocity = –0.23 m/s	change in velocity = ____________
time interval over which the force is applied = 0.10 s **Note: This is not displayed on the simulation.*	time interval over which the force is applied = 0.10 s **Note: This is not displayed on the simulation.*

calculate the acceleration of skater 1 $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$ $\vec{a} = \frac{-0.23 \text{ m/s}}{0.10 \text{ s}}$ $\vec{a} = -2.3 \text{ m/s}^2$	calculate the acceleration of skater 2 $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$
mass of skater 1 = 60.0 kg	mass of skater 2 = ___________
calculate the force applied to skater 1 $\vec{F} = m\vec{a}$ $\vec{F} = (60.0 \text{ kg})(-2.3 \text{ m/s}^2)$ $\vec{F} = -1.4 \times 10^2 \text{ N}$	calculate the force applied to skater 2 $\vec{F} = m\vec{a}$ * *Round your answer to 2 significant digits.*

LAB 2. What do you notice about the magnitude of the force applied to each skater?

LAB 3. What do you notice about the direction of the force applied to each skater?

LAB 4. Restate Newton's third law using the force values you calculated for each skater.

Conclusion

You saw that each skater was acted on by a force. You also saw that the magnitudes of these two forces were equal. The difference in the forces was their directions, which were opposite, and the fact that each force acted on a different person.

Read

Read pages 159 to 161 of your textbook. Look for significant differences between Newton's third law and the two laws you previously studied.

Self-Check

SC 1. Complete the following sentence by filling in the blank. In Newton's third law, the two forces not only act in different directions, they also act on different __________.

Check your work with the answer in the appendix.

Read

What happens when forces are exerted between objects that are separated and do not touch each other? Read "Action-Reaction Forces Acting on Objects in Contact" and "Action-Reaction Forces Acting on Objects Not in Contact" on pages 161 to 163 of your textbook. Look for significant differences between the two situations.

Self-Check

SC 2. What are two situations where action-reaction forces act on objects that are not in contact?

Check your work with the answer in the appendix.

Read

Have you ever moved an object without touching it by pushing on other objects that were in contact with it? How are Newton's laws involved in what happens? Read "Applying Newton's Third Law to Situations Involving Frictionless Surfaces" and "Applying Newton's Third Law to Situations Involving Friction" on pages 164 to165 of your textbook to see how the calculations are done. You will learn more in Module 3: Lesson 4 about the free-body diagrams used in these examples.

Self-Check

SC 3.

a. What are three forces exerted on box B in "Example 3.12" on page 164 of your textbook?
b. What are three forces exerted on box B in "Example 3.13" on page 165 of your textbook?

Check your work with the answer in the appendix.

Read

What are the action-reaction pairs in propeller aircraft and rockets? Read pages 166 and 167 of your textbook. Look for significant differences between propeller aircraft and rockets.

Self-Check

SC 4.

a. What is the action-reaction pair that provides thrust in propeller aircraft?
b. What is the action-reaction pair that provides thrust in rockets?

Check your work with the answer in the appendix.

Try This

Go to **www.learnalberta.ca**. You may be required to input a username and password. Contact your teacher for this information. Enter the search terms "Momentum Conservation" in the search bar. Choose the item called "Momentum Conservation (Grades 11 and 12)." Open the simulation to complete the following questions.

TR 1. Two hockey players are standing at centre ice. One player with a mass of 75.0 kg pushes the other player with a mass of 95.0 kg. Which player will move away with a greater acceleration? Why? Verify your answer using the applet.

Module 3: Lesson 2 Assignment

Remember to submit the answers to TR 2 and TR 3 to your teacher as part of your Lesson 2 Assignment in your Module 3 Assignment Booklet.

TR 2. Two basketball players run into each other. Player 1, with a mass of 55.0 kg, experiences a $-15.6\ m/s^2$ acceleration. If player 2 has a mass of 48.5 kg, what acceleration did she experience immediately following the collision?

TR 3. Complete the following table. The first row has been completed as an example.

Action	Action Force	Reaction Force
A bullet is fired from a gun by the expanding gases.	expanding gases pushing on the bullet	bullet pushing back on the expanding gases
A volleyball is served.	player's hands exerting a forward force on the ball	
The Moon orbits Earth.		moonward pull of the Moon acting on Earth
A firewoman opens the fire hose, and water sprays forward.		
A sprinter's shoe hits the ground.		

Self-Check

SC 5. Solve problem 8 of "3.4 Check and Reflect" on page 168 of the textbook.

Check your work with the answer in the appendix.

Watch and Listen

Go to your Physics 20 Multimedia DVD, and watch the video called "Newton's Laws Part 4" that explains the significance of Newton's laws.

Module 3: Lesson 2 Assignment

Remember to submit the answers to TR 4, TR 5, and TR 6 to your teacher as part of your Lesson 2 Assignment in your Module 3 Assignment Booklet.

Reflect and Connect

Knowing Newton's laws, how could a child holding a physics textbook get off of a perfectly frictionless sheet of ice?

Try This

TR 4. Sketch a diagram to show how an action-reaction pair of forces could be used to move across a frictionless surface.

TR 5. Explain where the forces originate and how the child could minimize the time it takes to get off the frictionless sheet of ice.

TR 6. Compare and contrast the child's strategy for getting off the ice with the operating principles of a rocket engine. In your answer indicate what a rocket engine throws out that serves a similar purpose to the textbook used in the child's strategy.

Module 3: Lesson 2 Assignment

Remember to submit the answers to D 1 and D 2 to your teacher as part of your Lesson 2 Assignment in your Module 3 Assignment Booklet.

Discuss

Go to page 141 of your textbook, and read "3-4 Decision-Making Analysis: The Airbag Debate." Consider Newton's third law, where every action has an equal and opposite reaction.

D 1. Answer question 3 of "Analysis" on page 141 of the textbook. Post your solution to the airbag issue to the discussion area, and respond to postings from at least two other students. If you wish to change your answers before submitting them to your teacher, do so.

D 2. Answer question 4 of "Analysis" on page 141 of the textbook. Post your proposed changes to the airbag design to the discussion area, and respond to postings from at least two other students. If you wish to change your answers before submitting them to your teacher, do so.

Reflect on the Big Picture

Each of the Reflect on the Big Picture sections in this module will ask you to consider the movement of people or goods. To help you reflect on your learning experience in this lesson, complete at least one of the following activities:

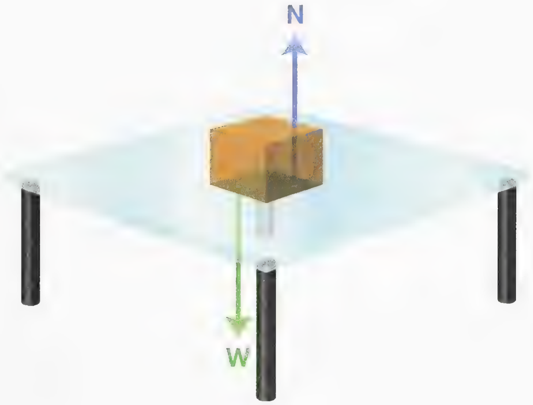
- Friction is both a help and a hindrance to transporting people and products. Without friction, it would be impossible to walk. But frictional forces make machines less efficient. Research how the Inuit solved the friction problem on their komatiks (sleds).

- Create a list of action-reaction pairs that you see when a child rides a bicycle. Choose at least two of the pairs, and make a textual, audio, or video presentation detailing how the reactive force helps the cyclist get to his or her destination.

Store your completed reflection in your Physics 20 course folder.

Going Beyond

A block is resting on a table as illustrated. The normal force (N), which is the supporting force of the table, is equal in magnitude but opposite in direction to the force of gravity or the block's weight (W). At first glance, this appears to be an application of Newton's third law. In fact, it is not.



Self-Check

SC 6. Explain why this illustration is not an example of Newton's third law. (**Hint:** Think about what object the forces are acting on, and compare this to the forces acting on the two skaters that you studied earlier in the lesson.)

Check your work with the answer in the appendix.

Module 3: Lesson 2 Assignment

Make sure you have completed all of the questions for the Lesson 2 Assignment. Check with your teacher about whether you should submit your assignment now or wait until all of the Module 3 assignments have been completed.

Lesson Summary

As you worked through this lesson, you should have developed answers to these questions:

- How do Newton's laws help explain why motion occurs?
- How do you find a reaction force?
- How does friction affect moving objects?

In contrast to the kinematic equations that describe motion, Newton's laws explain why motion occurs the way it does. Newton's third law explains how two bodies interact with an action-reaction force pair. For every action force, a reaction force exists that is equal in magnitude but opposite in direction.

In this lesson you were mostly able to ignore friction. In the next lesson you will learn more about friction, a significant factor that should not be ignored.

Lesson Glossary

friction: the resistance to motion between two surfaces in contact

Lesson 3—Normal Force and Friction

Get Focused

In 2006, Canadian National Railways took delivery of 35 new locomotives produced by General Electric. The locomotive pictured here is from GE's new Evolution Series Transportation System of new diesel locomotives that meet the environmental standards that took effect in 2005. The **ES44DC** (**E**volution **S**eries **44**00-hp **DC** transmission) uses a 12-cylinder engine that delivers the equivalent power of an older 16-cylinder engine while consuming less fuel and producing fewer emissions. The energy from the 12-cylinder diesel engine is converted into direct current, which powers the electric motors that turn the wheels.

cc Peter Borcherd

This particular locomotive generates 4400 horsepower! Most of this power is needed when the train is accelerating forward. When it is moving at a constant speed, much less power is needed. Exactly how much power is needed depends on several factors, including the mass of the train, the desired acceleration, any incline in the tracks, and the friction that opposes the motion of the train. More friction leads to less efficiency and more power consumption. One of the advantages of rail transportation is the ability to travel on low-friction surfaces, like steel tracks. Why is this? How do you determine the amount of friction to overcome in a moving system like that of the railway?

In this lesson you will have a brief introduction to free-body diagrams and explore the nature of the normal force and its relationship to weight. You will also graphically determine an expression for kinetic friction and calculate kinetic, static, and rolling friction in a variety of situations.

As you work through this lesson, keep the following questions in mind:

- How does friction affect moving objects?
- How does friction affect making an object move?
- How do free-body diagrams, vector analyses, and Newton's second law help solve moving-object problems?

Module 3: Lesson 3 Assignments

In this lesson you will complete the Lesson 3 Assignment in the Module 3 Assignment Booklet.

- Lab—LAB 1, LAB 2, LAB 3, LAB 4, and LAB 5
- Try This—TR 4 and TR 5
- Reflect and Connect

You must decide what to do with the questions that are not marked by the teacher.

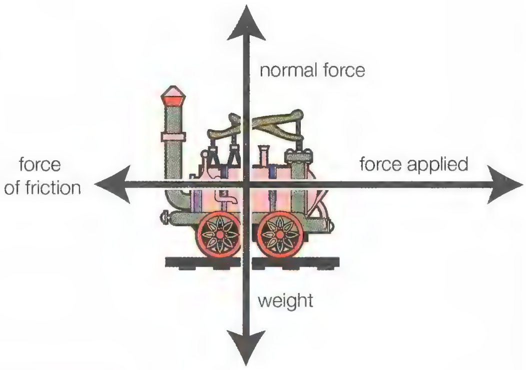
Remember that these questions provide you with the practice and feedback that you need to successfully complete this course. You should respond to all the questions and place those answers in your course folder.

Explore

Introduction to Free-Body Diagrams

In previous applications of Newton's second law, you solved problems where only one force was acting. It is not uncommon to have multiple forces acting on a single mass at one time.

For example, when a train is travelling along the tracks, the engine produces an applied force; a frictional force resists the engine force; a gravitational force (or **weight**) pulls down; and the ground provides a supportive, upward force (or **normal force**). All of these forces are illustrated here.



weight: a measure of the force of gravity on an object

normal force: the perpendicular force that a surface exerts on an object with which it is in contact

free-body diagram: a drawing of a system with forces acting on it

In physics, this diagram will be turned into a **free-body diagram**, where all forces originate from the object's approximate centre of mass but maintain their relative directions and magnitudes.

Before you explore free-body diagrams in detail, you will first investigate the common kinds of forces that should be included in such analyses. Common forces you will need to know include the following:

- *Weight* ($\vec{W}$) is the force that results from the action of gravity on matter. According to Newton's second law, if $F = ma$, then $W = mg$, where g is the acceleration due to gravity. Weight (force in newtons) should not be confused with mass (kilograms), although the terms are commonly mixed up. Weight is an expression of the pull of gravity on an object. In an environment where there is no gravity, an object

would be weightless. *Mass*, however, is a measure of the amount of matter in an object (not to be confused with volume, which is the space an object occupies) and will *not change* under varying gravitational forces.

- *Normal force* ($\vec{N}$ or $\vec{F}_N$) is one component of the force that a surface exerts on an object with which it is in contact, namely the component that is perpendicular to the surface. When the surface of contact is horizontal, the normal force is equal in magnitude but opposite in direction to the weight of the upper object. The word *normal* in free-body diagrams is a synonym for *perpendicular* or *right-angled.*

- *Friction* ($\vec{F}_f$) is the force that opposes the relative motion or tendency of such motion between two surfaces that are in contact. Friction is parallel to the surface and is directed opposite to motion.

- *Applied force* ($\vec{F}_{app}$) is a general term used to describe a force generated from a person, motor, or other object.

Normal Force and Weight

Normal force is a supporting force that acts between two surfaces that are in contact. For example, the railway tracks that a train travels on exert an upward force on the wheels of the train, preventing it from falling into the tracks and the ground below. Determining the normal force requires an application of Newton's second law.

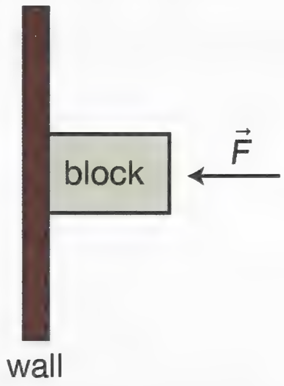
Watch and Listen

Go to your Physics 20 Multimedia DVD, and complete the tutorial called "Normal Force & Friction Force."

Try This

TR 1. The animation and associated text (viewed by clicking the T on the animation) will either provide the answers directly or will provide the basic information that needs to be applied to find the answers for the following questions.

a. What is the significance of the word *normal* in normal force?



b. A block is being pressed against a vertical wall by means of an applied force. The arrow represents the applied force. In what direction is the normal force exerted by the wall on the block?

c. Along what surface does the normal force act to support an object?

d. When a book is resting on a table, the normal force exerted by the table on the book depends on the weight of the book. What is the physical mechanism that causes the normal force to be smaller in one case and larger in another? In other words, what is different about the table and/or the book such that the normal force is smaller for one book and larger for another book?

e. Is there an expression for the normal force that one object exerts on another, like the expression for the gravitational force (e.g., $\vec{F} = m\vec{g}$) that one object exerts on another? If so, what is this expression? If not, how can one calculate the normal force in a given situation?

f. What is the physical origin of the normal force? For example, what enables a table to push upward on a book that is resting on the table?

g. Describe the relationship between the size of the normal force and the amount of compression in the upper layers of the table molecules when various weights are placed on a table.

Friction

Friction is the force that opposes the relative motion, or tendency of such motion, of two surfaces that are in contact. For example, there is friction between the wheels of a train and the track they are in contact with. The friction opposes the motion of the train, and work must be done to overcome the force of friction.

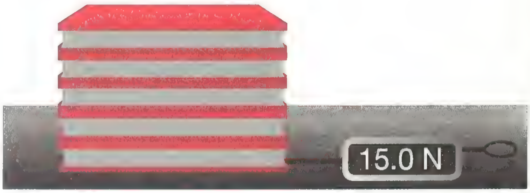
Watch and Listen

Go to your Physics 20 Multimedia DVD, and complete the tutorial called "Coefficient of Friction." This tutorial will help you understand how the force of friction is generated and how it contributes to the net force acting on an object. Click the right arrow in the bottom right-hand corner to progress to the next screen when you are ready.

- **Page 1:** You will be presented with a question and a white answer box. Click in the box, type the numerical value of your answer, and select Enter on your keyboard. Repeat for the next question posed.
- **Page 2:** Run the animation before you try to place the weight arrow.
- **Page 4:** Run the animation before you try to place the weight arrow.
- **Page 5:** If you choose the wrong surface, you get a red X. Go back one screen, and try again.

Lesson 3 Lab: Friction

The applet used for this lab lets you simulate the force exerted on a spring (force) scale as it pulls a stack of books across a rough table surface. You can learn more about the simulation and how to use it by reading Show Me found at the top of the simulation screen.



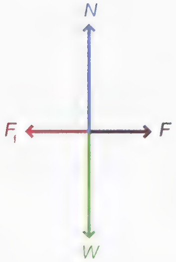
Problem 1

What is the difference between kinetic friction and static friction?

Go to **www.learnalberta.ca**. You may be required to input a username and password. Contact your teacher for this information. Enter the search term "Friction" in the search bar. Choose the third item (applet) called "Friction (Grade 11)." Open the simulation; then continue with the procedure.

Procedure

- Using the simulation, stack 5 books, which are attached to the force scale as shown. Use the button to add a book.



- Click in the "Show FBD" square (✓ **Show FBD**) at the top to toggle on the free-body diagram. Note the behaviour of the FBD as you pull on the open ring of the force scale attached to the bottom book. The red vector represents the frictional force ($\vec{F}_f$), and the brown vector represents the applied force ($\vec{F}_{app}$).
- Using the mouse, slowly pull on the open ring of the force scale and observe the reading on the scale just as the stack of books begins to move. Notice that once the books begin to move, the force required to keep the books moving reduces.

Observations and Analysis

Module 3: Lesson 3 Assignment

Remember to submit the answers to LAB 1, LAB 2, and LAB 3 to your teacher as part of your Lesson 3 Assignment in your Module 3 Assignment Booklet.

LAB 1. What is the maximum force applied *before* the books start to move?

LAB 2. What is the applied force required to *keep* the books moving?

Before the stack of books begins to move, the force of friction is called **static friction**. After the motion begins, the stack of books is subject to **kinetic friction**. Note that kinetic friction is smaller in magnitude than static friction.

static friction: the friction between two objects that are in contact but are not moving

kinetic friction: the type of friction that an object is subject to after it is in motion

LAB 3. Complete the following questions.

a. What happens to the size of the static frictional force as you start to pull on the force scale?

b. Is there a maximum size for the static frictional force? If so, what happens to the object if the applied force exceeds the maximum static frictional force?

c. Is there a minimum size for the static frictional force? If so, under what conditions will this force be a minimum?

d. What type of frictional force acts when the system is at rest?

Problem 2

What is the mathematical expression for kinetic friction?

Go to **www.learnalberta.ca**. You may be required to input a username and password. Contact your teacher for this information. Enter the search term “Friction” in the search bar. Choose the third item (applet) called “Friction (Grade 11).” Re-open the simulation; then continue with the procedure.

Procedure

The force of friction arises from an interaction between surfaces. In the case of the books and rough table surface, the table surface exerts a force on the bottom book. This force is the normal force (F_N) and is represented in blue. Opposing the normal force is the object's weight. The weight (W) is represented in green. For the books resting on the table, the normal force is equal in magnitude to the weight. The normal force and weight are "balanced." The magnitude of the normal force can be calculated by equating it to the weight. For example,

$$F_N = W$$
$$F_N = mg$$

Even though friction is an extremely complex phenomenon, there is a very simple relationship between the magnitude of the frictional force and the normal force.

Observations and Analysis

Module 3: Lesson 3 Assignment

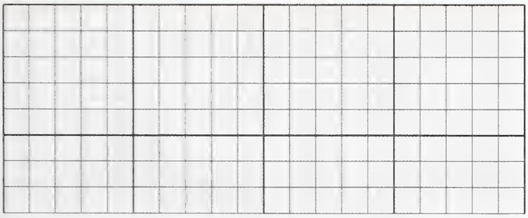
Remember to submit the answers to LAB 4 and LAB 5 to your teacher as part of your Lesson 3 Assignment in your Module 3 Assignment Booklet.

LAB 4. Using the applet, measure the applied force required to keep the books moving. Then complete the following table. To calculate the normal force, assume that each book has a mass of 1.00 kg. Use the - button to remove books, and use the “Reset” button to start over.

Number of Books	**Normal Force (N)** $F_N = mg$	Kinetic Frictional Force (N)
1	________	________
2	________	________
3	________	________
4	________	________
5	________	________
6	________	________
7	________	________
8	________	________
9	________	________
10	________	________

LAB 5. Complete Graph 1 by plotting the normal force on the *x*-axis (manipulated variable) and the kinetic frictional force on the *y*-axis (responding variable). Label the graph appropriately.

Graph 1: Kinetic Frictional Force vs. Normal Force



LAB 6. Complete the following questions.

a. Which of the following alternatives best describes Graph 1: Kinetic Frictional Force vs. Normal Force?

A. The graph is constant and of the mathematical form $y = b$, where b is constant.
B. The graph is linear and of the mathematical form $y = mx + b$, where b is zero and m is the slope.
C. The graph is a quadratic curve and of the form $y = ax^2 + bx + c$, where a, b, and c are coefficients.

b. Use your answer to LAB 6.a. to write an equation expressing the relationship between kinetic frictional force and the normal force.

The equation you derived in LAB 6 should have the form $y = mx$, where m is the slope of the equation. This means that the equation for the kinetic frictional force is $F_{f_{kinetic}} = \mu_k F_N$, where

- $F_{f_{kinetic}}$ equals the magnitude of the kinetic force of friction (y-axis)
- F_N equals the magnitude of the normal force (x-axis)
- μ_k equals the **coefficient of kinetic friction** (slope)

coefficient of kinetic friction: ratio of friction force to normal force once two objects in contact stop moving as one object

LAB 7. Using Graph 1, calculate the coefficient of kinetic friction (μ_k) for the book-table interface. According to the slope calculations, does μ_k have any units?

Conclusion

Frictional forces are complicated. They depend not only on the two objects involved but also their conditioning at the moment of the interaction of the two objects. For example, roads made of asphalt become very slippery when freezing rain or snow covers the surface, and tires lose their grip when they are worn. Furthermore, even if all these circumstances are fixed, the frictional force also depends on whether an object slides (kinetic) or is stationary (static) with respect to the other surface. This gives rise to two basic forms of friction.

Kinetic Friction

When an object slides, it experiences a frictional force, $F_{f_{kinetic}} = \mu_k F_N$.

Notice that the formula only involves magnitudes of forces. There is no vector sign above the F. The directions must be determined separately.

Kinetic frictional force always opposes motion. It acts opposite to the direction of motion.

Static Friction

When an object is at rest, a static frictional force resists motion.

$$F_{f_{static}} = \mu_s F_N$$

The formulas for the two different types of friction are similar. But the constants of friction differ. To find the $F_{f_{kinetic}}$, the coefficient of kinetic friction (μ_k) is used. To find the $F_{f_{static}}$, the **coefficient of static friction** (μ_s) is used. F_N is the magnitude of the normal force in both formulas.

coefficient of static friction: ratio of the maximum friction force to normal force while two objects in contact move as one object

The maximum static frictional forces are larger than the kinetic frictional forces.

Read

What influences the coefficient values for static friction and kinetic friction? Read pages 180 to 184 of your textbook to learn more. The lug tread shown on page 184 has more traction in soft soil than the ribbed tread. Even the composition of the rubber makes a difference. For example, the rubber used for making winter tires is softer than the rubber used for summer tires.

Self-Check

SC 1.

a. Which of the materials listed in “Table 3.4” on page 183 of your textbook has the second highest coefficient of static friction?

b. Which of the materials listed in “Table 3.4” has the lowest coefficient of kinetic friction?

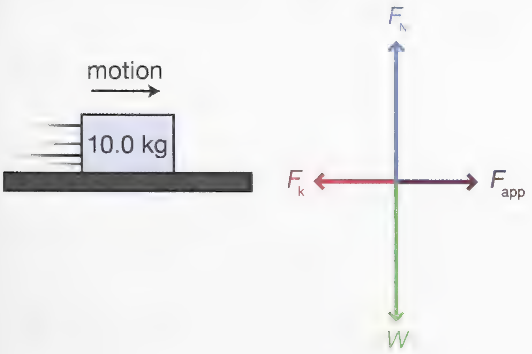
Check your work with the answer in the appendix.

Determining the magnitude of the force of friction depends on the situation. Common examples and problem-solving methods are presented below.

Example Problem 1

The coefficient of kinetic friction between a block and the level surface it slides on is 0.45. If the mass of the block is 10.0 kg, what is the magnitude of the force needed to keep the block moving with uniform motion?

Solution



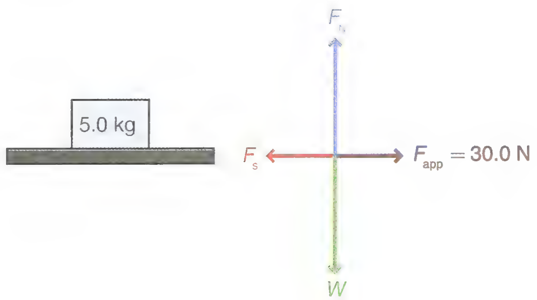
$$\begin{aligned} F_{f_{\text{kinetic}}} &= \mu_k F_N \\ &= \mu_k (mg) \\ &\doteq (0.45)(10.0\ \text{kg})(9.81\ \text{m/s}^2) \\ &\doteq 44.145\ \text{N} \\ &= 44\ \text{N corrected to 2 significant digits} \end{aligned}$$

The applied force must balance the kinetic frictional force in order to maintain uniform motion. The magnitude of the force needed to keep the block moving with uniform motion is 44 N.

Example Problem 2

A student pulls on a 5.00-kg object and discovers that she needs to exert 30.0 N of force before the object moves. What is the coefficient of static friction between the object and the surface on which it rests?

Solution



Since the applied force is 30.0 N *just* before moving, the frictional force must be equal in magnitude to the applied force. Therefore,

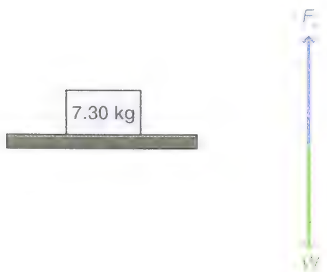
$$\begin{aligned} F_{f\ static} &= \mu_s F_N \\ \mu_s &= \frac{F_{f\ static}}{F_N} \\ &= \frac{F_{f\ static}}{(mg)} \\ &= \frac{30.0\text{ N}}{(5.00\text{ kg})(9.81\text{ m/s}^2)} \\ &= 0.612 \end{aligned}$$

The coefficient of static friction is approximately 0.612.

Example Problem 3

A 7.30-kg box is at rest on a level table. The coefficient of static friction between the box and table is 1.03. How big is the static frictional force?

Solution

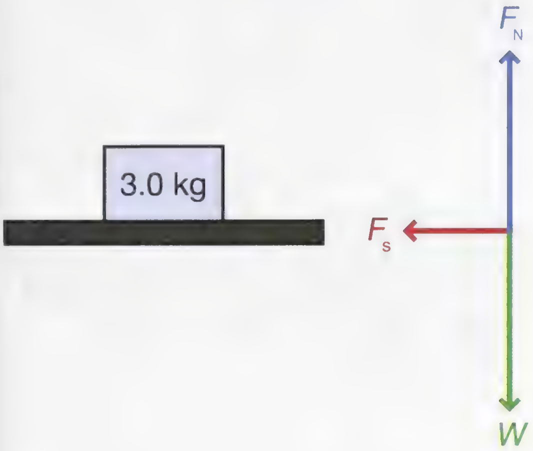


There is no static frictional force acting since there is no net force attempting to move the box.

Try This

TR 2. Devise a method to determine the coefficient of static friction used in the simulation. Explain how you found the coefficient, and give its value.

TR 3. A student drew a free-body diagram for a box sitting at rest on the floor. Explain what is wrong with this diagram.



Read

"Example 3.17" on page 185 of your textbook shows how to determine mass from frictional forces on a sled, and "Example 3.19" on pages 187 and 188 of your textbook shows how to determine acceleration of a skidding vehicle. Use the two examples to help solve the following Self-Check question.

Self-Check

SC 2. Go to page 190 of your textbook and complete question 6 of "3.5 Check and Reflect."

Check your work with the answer in the appendix.

Module 3: Lesson 3 Assignment

Remember to submit the answers to TR 4 and TR 5 to your teacher as part of your Lesson 3 Assignment in your Module 3 Assignment Booklet.

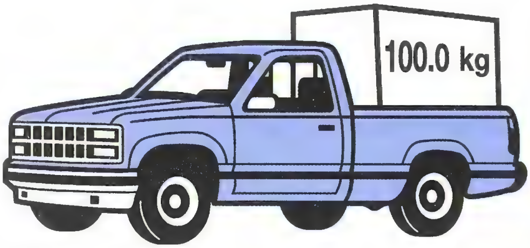
Try This

TR 4. The coefficient of static friction between a book and the level surface it slides on is 0.65. If the mass of the book is 2.0 kg, what minimum initial applied force is required to slide the books across the surface?

TR 5. An engine provides 5.0 kN of force to keep a 1600-kg vehicle moving at a uniform speed. (Air resistance is negligible.) What is the coefficient of rolling friction between the tires and the road surface?

Self-Check

SC 3. A 100.0-kg crate is at rest in the back of a truck. If the coefficient of static friction between the crate and the truck bed is 0.30, what is the maximum acceleration that the truck can have before the crate begins to slide? Draw a free-body diagram, and explain what force causes the crate to accelerate along with the truck.

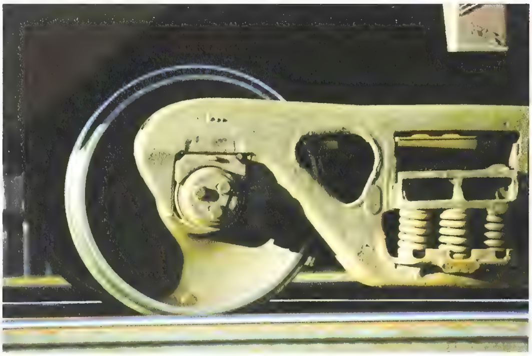


Check your work with the answer in the appendix.

Module 3: Lesson 3 Assignment

Remember to submit the answer to the Reflect and Connect to your teacher as part of your Lesson 3 Assignment in your Module 3 Assignment Booklet.

Reflect and Connect



The amount of friction between train wheels and the track is based on the normal force and the coefficient of friction between the dry steel of the wheel and the dry steel of the track.

The coefficient of friction for steel on dry steel is 0.41 (static) and 0.38 (kinetic).

The GE Evolution series locomotive has a mass of 188 000 kg. Determine the amount of static and kinetic friction force available to the wheels. Is this force equivalent to the maximum braking force, the maximum useful engine force, or both?

Discuss

© Kharidehal Abhirama Ashwin/shutterstock

The antilock brakes prevent car tires from locking up and skidding. Research how antilock braking systems work, and identify their strengths and weaknesses. When you go to the discussion area, be sure you can explain why a car can stop faster and safer if the tires do not skid.

D 1. Post an experience you or someone you know has had where antilock brakes were used.

D 2. Post an analysis of the strengths and weaknesses of the antilock braking system. Use diagrams where appropriate in your posting.

Reflect on the Big Picture

Each of the Reflect on the Big Picture sections in this module will ask you to consider the movement of people or goods. To help you enhance your learning experiences for this lesson, complete at least one of the following activities:

- Take or find a series of photos of a corner with traffic lights or a stop sign that illustrate the forces acting on the vehicles and their passengers. Think up captions for the photos that would help you remember how the forces were working.

- In car-chase scenes of action movies, you often hear vehicles screeching around corners. In normal driving situations, you don't want to treat your vehicle so poorly. Create a free-body diagram to help analyze the forces acting on a car skidding around a corner. Contrast this with a free-body diagram of an everyday turn.

Store your completed reflection in your Physics 20 course folder.

Module 3: Lesson 3 Assignment

Make sure you have completed all of the questions for the Lesson 3 Assignment. Check with your teacher about whether you should submit your assignment now or wait until all of the Module 3 assignments have been completed.

Lesson Summary

As you worked through this lesson, you should have developed answers to these questions:

- How does friction affect moving objects?
- How does friction affect making an object move?
- How do free-body diagrams, vector analyses, and Newton's second law help solve moving-object problems?

There are many different kinds of forces that can act on a single mass. A free-body diagram is used to illustrate and understand how multiple forces acting on a single mass contribute to the net force and acceleration of that mass. The following common forces will be used in free-body analysis.

- An object's weight is the force that results from the action of gravity on matter. According to Newton's second law, if $F = ma$, then weight is defined by $W = mg$, where g is the acceleration due to gravity.

- The normal force is a supporting force that acts between two surfaces in contact. On a flat, horizontal surface, the normal force can be determined by an application of Newton's second law ($F = mg$) since it opposes all of the object's weight.

- Friction is the force that opposes the relative motion or tendency of such motion of two surfaces that are in contact. The mathematical expression for friction depends on whether the mass is moving (kinetic) or stationary (static).

If an object slides, it experiences a kinetic frictional force given by $F_{f_{\text{kinetic}}} = \mu_k F_N$. If an object is at rest, a static frictional force resists motion. The maximum static frictional force is given by $F_{f_{\text{static}}} = \mu_s F_N$.

Lesson Glossary

coefficient of kinetic friction: ratio of friction force to normal force once two objects in contact stop moving as one object

coefficient of static friction: ratio of the maximum friction force to normal force while two objects in contact move as one object

free-body diagram: a drawing of a system with forces acting on it

kinetic friction: the type of friction that an object is subject to after it is in motion

normal force: the perpendicular force that a surface exerts on an object with which it is in contact

static friction: the friction between two objects that are in contact but are not moving

weight: a measure of the force of gravity on an object

Lesson 4—Free-Body Diagrams and Net Force

Get Focused

Can you identify all the forces acting on this ambulance? Recall the three accelerators on a vehicle—engine, brakes, and steering. Each of these vehicle components can cause acceleration by generating a force that contributes to the overall net force and observed acceleration of the ambulance.

© Aaron Kohr/shutterstock

In this photo the ambulance is observed to be accelerating forward, which, according to Newton's second law, means that the applied force of the engine is greater than the force of friction opposing the motion. Notice also that the ambulance is not sinking into the ground or taking off like an airplane. Does that mean that there are no vertical forces acting on the ambulance? Not necessarily. The ambulance has a significant weight that must be supported by the ground. So, there are vertical forces, but they are balanced.

Upon quick inspection, there is an applied force of the engine, the force of friction opposing the forward motion, the ambulance weight, and the supporting normal force—all acting at the same time.

Is there a quick and easy way to visualize all the forces at once and generate an equation that describes the net force and observed acceleration of a vehicle, such as an ambulance?

In the previous lesson you worked with free-body diagrams in limited situations. In this lesson you will construct labelled free-body diagrams for objects in a variety of physical situations and use the diagrams to derive net-force equations that describe the observed acceleration of the object.

Module 3: Lesson 4 Assignments

In this lesson you will complete the Lesson 4 Assignment in the Module 3 Assignment Booklet.

- Try This—TR 1, TR 2, and TR 3

You must decide what to do with the questions that are not marked by the teacher.

Remember that these questions provide you with the practice and feedback that you need to successfully complete this course. You should respond to all the questions and place those answers in your course folder.

As you work through this lesson, keep the following questions in mind:

- How is the motion of an object affected by the forces applied to it?
- How do unbalanced forces affect the motion of an object?
- How do free-body diagrams, vector analyses, and Newton's second law help solve moving-object problems?

Explore

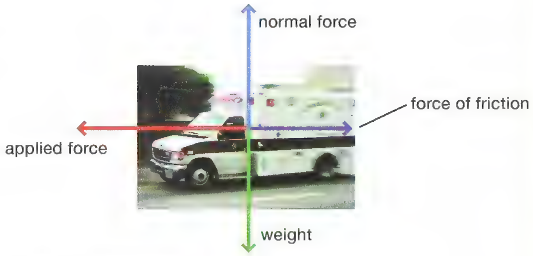
What Is a Free-Body Diagram?

The ambulance pictured in Get Focused is speeding to an emergency. It has multiple forces acting upon it at the same time:

- an applied force from the engine
- the force of friction between the tires and the road
- the ambulance weight (the force of gravity)
- the "normal" or supporting force of the road
- the force of air resistance
- forces generated from the braking and steering systems

All of these forces act to determine how the ambulance will accelerate according to Newton's second law. The acceleration, in turn, describes how the velocity of the ambulance will change in magnitude and direction. In order to simplify and understand how these forces act together, you will need an analytical tool in the form of a free-body diagram. What is a free-body diagram?

- A free-body diagram is an indispensable tool used in the analysis of forces and the application of Newton's laws.
- A free-body diagram is a representation of all the forces acting on a body.
- If a system consists of more than one object, then it is essential that a free-body diagram be constructed for each object.



© Aaron Kohr/shutterstock

With practice and careful attention to detail, making a free-body diagram is an easy process; and it will greatly improve your ability to understand complex physical situations.

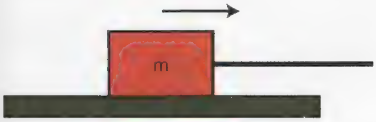
Read

To get a better picture of how free-body diagrams are done correctly, read pages 129 to 131 of your textbook starting at "Representing Forces Using Free-Body Diagrams." This will prepare you for the following lab activity.

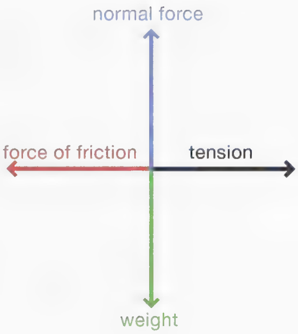
Lesson 4 Lab: How to Draw Free-Body Diagrams

Go to your Physics 20 Multimedia DVD, and use the simulation called "Free-Body Drawer" to create free-body diagrams (FBD). The applet used for this lab lets you explore free-body analysis by constructing various free-body diagrams and comparing them to computer-generated models.

You can learn more about how to use the simulation by reading the Show Me. You can access this file by opening the simulation and selecting Help in the upper left-hand corner. Choose Applet Help, and then select Show Me found at the top of the Applet Help screen. You may be required to login with a username and a password. Contact your teacher for this information.



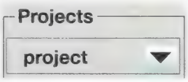
A block is pulled to the right at a steady speed on a rough surface.



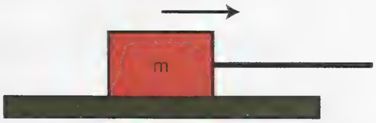
With the Free-Body Drawer simulation open, continue with the lab questions.

Procedure

- Select "project" from the drop-down menu at the top right-hand corner of the simulation.



- The following diagram should be showing on the simulation. Note that there will be no forces shown on the display at this point.



A block is pulled to the right at a steady speed on a rough surface.

- The correct free-body diagram for this situation would show four forces:
  - the gravitational force (weight of the block)
  - the supporting (normal) force of the surface pressing up on the block
  - the frictional force opposing the motion of the block (In this case, it will be to the left.)
  - the force (tension) applied by the rope (directed to the right)

- Make sure "Draw New Vectors" is selected (◉ **Draw New Vectors**), and begin to draw the forces by clicking and dragging them one by one from the centre of the block in the desired direction.

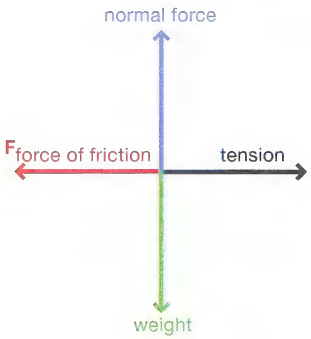
- Remember to name each vector appropriately immediately after each one is drawn by typing the name in the "Selected Vector Name" rectangle

  (**Selected Vector Name** vector 1)

- When all four vectors are drawn, verify your FBD (free-body diagram) by pressing "Check" (✓ **Check**) and selecting "FBD" (**FBD**).

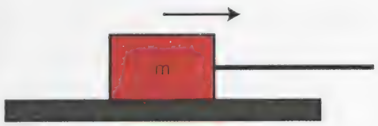
- You can reposition your vectors using the "Set Vector Origin(s)" option (◉ **Set Vector Origen(s)**) on the right. Make sure you have highlighted the vector you want to move in the "Vectors" chart (vectors weight 1). The vector will move to wherever you click your cursor. In a similar way, you can reposition the head of a vector using the "Set Vector Head(s)" option (◉ **Set Vector Head(s)**).

Look carefully at the FBD for this example. A common practice (but not essential) is to draw a set of vectors emerging from a single point and extending away from the original diagram.



Since the surface is level, the normal force and the weight are equal and acting in opposite directions. Also, since the block is *not accelerating* ("travelling at a steady speed" being the same as having zero acceleration), the net horizontal force is zero. This means that the frictional force is equal in magnitude and opposite in direction to the tension force applied by the rope. In all directions the net force is zero. Note that a zero net force, and thereby a zero acceleration, does not mean that an object is not moving—it just means that the motion is uniform. (It maintains a constant velocity or "steady speed.")

Using the simulation, select the figure shown below using the "Image" button (**Image**) and choosing the second FBD. Click OK. (Note that the text below the block now indicates that it is accelerating.) On the display, draw and name all of the forces you think are acting on this block. Verify your FBD by clicking the "Check" button (**Check**) and selecting "FBD" (**FBD**). Draw the correct FBD for this situation on the image.



A block is pulled with a steady force to the right and accelerating on a rough surface.

Self-Check

SC 1. Are all of the forces balanced? Explain why or why not.

Check your work with the answer in the appendix.

How to Create Equations from Free-Body Diagrams

Using free-body diagrams, it is possible to generate equations that can be used to predict the magnitude and direction of forces or accelerations, or both. The simulation will be used to demonstrate how this is done.

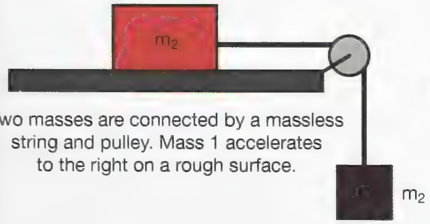
On the simulation, select an FBD using the "Image" button (**Image**) and selecting the upper right-hand FBD. Click OK. There are now two masses in the system; therefore, you must make two FBDs, one for each mass. On the applet display, draw and name all of the forces you think are acting on each block.

- The FBD for m_1 will be identical to the one you made in the procedure.
- The FBD for m_2 should show only two forces: weight and tension.

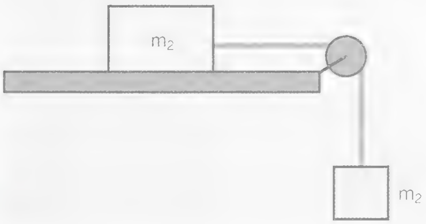
Verify your FBDs when you are done by clicking "Check" (**Check**) and selecting "FBD" (**FBD**).

Self-Check

SC 2. Draw the correct FBDs on a copy of the diagram on the right.



Two masses are connected by a massless string and pulley. Mass 1 accelerates to the right on a rough surface.



Check your work with the answer in the appendix.

Self-Check

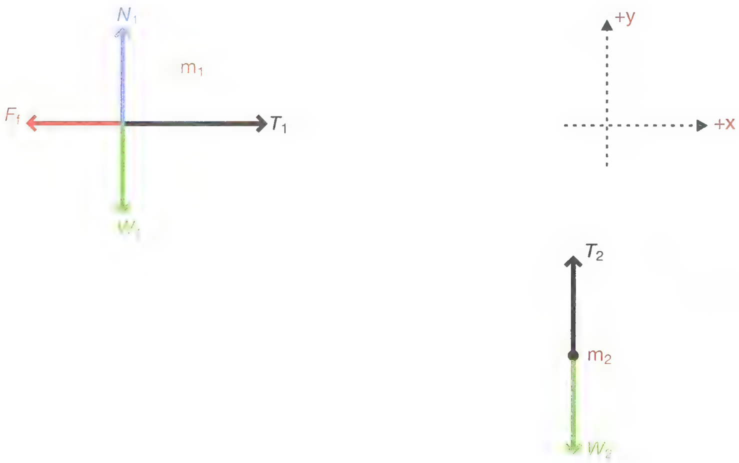
SC 3. Identify the coordinate axes on the diagram above and to the right, and explain in words what it means.

Check your work with the answer in the appendix.

Choosing coordinate axes is essential for correctly assigning the direction of each force. Any force pointing in the $+x$ or $+y$ directions will be treated as positive, and any force in the opposite directions will be treated as negative.

Self-Check

SC 4. The FDBs for the masses connected by a rope and pulley without mass, including coordinate axes, looks like this.



Use the words *positive* or *negative* in the blanks below to indicate the directions of the force vectors

a. $\vec{N}_1$ ____________________

b. $\vec{F}_f$ ____________________

c. $\vec{W}_1$ ____________________

d. $\vec{W}_2$ ____________________

e. $\vec{T}$ ____________________

Check your work with the answer in the appendix.

Now it is possible to write simple equations describing the forces along the *x*- and *y*-axis for each body. This is done using Newton's second law and the fact that the net force along each axis is always the sum of all the forces acting along that axis.

Equations for Mass 1

The net force along the *x*-axis is the sum of all forces acting along the *x*-axis. Tension points in the positive direction, and the force of friction is in the negative direction.

$$\vec{F}_{net} = \left(+\vec{T}\right) + \left(-\vec{F}_f\right)$$
$$\vec{F}_{net} = \vec{T} - \vec{F}_f$$

According to Newton's second law, $F_{net} = ma$. Therefore, the equation to determine the acceleration of the mass along the *x*-axis is

$$m\vec{a} = \vec{T} - \vec{F}_f$$

The net force along the *y*-axis is the sum of all forces acting along the *y*-axis. The normal force points in the positive direction, and the weight points in the negative direction. The mass is not accelerating in this direction; therefore, the magnitude of each of these vectors is identical and the net force along the *y*-axis must be zero.

$$\vec{F}_{net} = \left(+\vec{N}_1\right) + \left(-\vec{W}_1\right)$$
$$\vec{F}_{net} = \vec{N}_1 - \vec{W}_1$$
$$\vec{F}_{net} = 0$$

Equations for Mass 2

The net force along the y-axis is the sum of all forces acting along the y-axis. The tension force points in the positive direction, and the weight points in the negative direction. Also, mass 2 is accelerating in the downward direction; therefore, the y equation for mass 2 is

$$\vec{F}_{\text{net}} = \left(+\vec{T}\right) + \left(-\vec{W}_2\right)$$
$$\vec{F}_{\text{net}} = \vec{T} - \vec{W}_2$$
$$m\vec{a} = \vec{T} - \vec{W}_2$$

Finding Net Force Using Free-Body Diagrams

Read

How do you use free-body diagrams to find the net force when there is more than one force in a particular direction? Read "Using Free-Body Diagrams to Find Net Force" on pages 131 to 133 of your textbook.

Self-Check

SC 5. Go to page 132 of your textbook and complete question 1 of "Practice Problems."

Check your work with the answer in the appendix.

Module 3: Lesson 4 Assignment

Remember to submit the answers to TR 1 to your teacher as part of your Lesson 4 Assignment in your Module 3 Assignment Booklet.

Try This

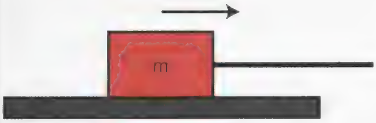
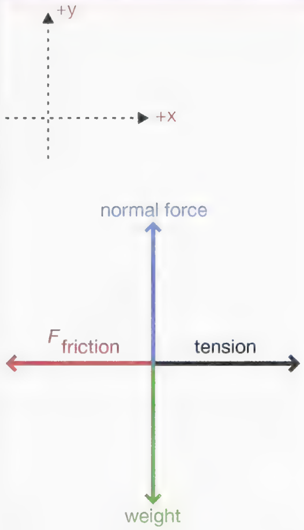
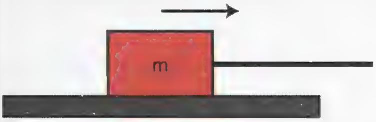
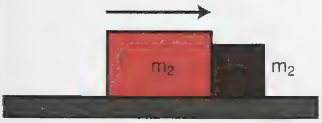
Go to your Physics 20 Multimedia DVD, and re-open the "Free-Body Drawer" simulation to work through the following questions.

TR 1. Select "project" from the drop-down menu titled "Projects" at the top of the applet. Load the images shown below using the "Image" button (Image), and complete the table by doing the following:

- Identify and list all of the forces in the system.
- Draw a correctly labelled free-body diagram (FBD).
- On your FBD, draw a convenient coordinate system and assign vector directions.
- Derive the relevant net force equations for the FBD as shown above.

The first project is done for you as an example.

You may print out the FBD and coordinate axis for each project by right-clicking on the diagram and selecting Print. You will be shown a preview screen. Click on the printer icon at the bottom, and select your printer (or print to file if you are sending your answer electronically). Click OK.

Project	List Forces	Draw FBD	Equations (m_1 and m_2)
 A block is pulled to the right at a steady speed on a rough surface.	normal force tension friction weight		$F_{net} = (+T) + (-F_f)$ F_{net} = zero ma = zero
 A block is pulled to the right and accelerating on a rough surface.			
 Two blocks in contact are pushed with a steady force to the right and accelerating on a rough surface.			
 Two blocks in contact are pushed at a steady speed to the right and accelerating on a rough surface.			

Working with Forces at an Angle Using Free-Body Diagrams

Read

All the forces you have considered to this point in the lesson have been parallel to each other or perpendicular. What if the forces occur at an angle to each other? The free-body diagrams are invaluable in sorting things out. Read pages 133 to 135 of your textbook starting at "Adding Non-Collinear Forces."

Self-Check

SC 6. In solving "Example 3.3" and "Example 3.4" of your textbook with non-collinear forces, one of the first steps in the solution was to draw a free-body diagram for the object. What was the very next step in both cases?

SC 7. Solve question 2 of "Practice Problems" on page 134 of your textbook.

Check your work with the answer in the appendix.

Module 3: Lesson 4 Assignment

Remember to submit the answer to TR 2 to your teacher as part of your Lesson 4 Assignment in your Module 3 Assignment Booklet.

Try This

TR 2. Solve question 5 of "3.1 Check and Reflect" on page 136 of your textbook.

Finding Net Force for Inclined Surfaces

If you took a summer job in construction that required you to work on a roof, the force of friction would be critical for your safety and productivity. Notice the young worker in the photograph has his foot on a board strapped to the roof for security. Even laying down a tool could be a challenge because it could slide away, which is very inconvenient. The tool may hit someone below, which could cause serious injury.

A roofer is working on an incline.

The forces on inclines also play a role in a host of fun activities such as snowboarding, water sliding, auto racing, skiing, skateboarding, and surfing. You have felt for yourself the dramatic difference in forces on inclines if you have ever ridden a bicycle uphill and then downhill.

In preparation for investigating free-body diagrams on inclines using the Free-Body Drawer simulation, get some background to assist you.

Read

How do you use free-body diagrams to find the net force on an incline? Read "Static Friction on an Incline" on pages 173 to 175 of your textbook. The red and blue broken line vectors are the components of the force of gravity (weight) of the object. The red vector ($\vec{F}_{g\parallel}$) is the component parallel to the slope, and the blue vector is the component perpendicular to the slope ($\vec{F}_{g\perp}$).

Self-Check

SC 8. Which component of the weight ($\vec{F}_g$) is equal in magnitude but opposite in direction to the normal force?

SC 9. In free-body diagrams of an object on an incline, what is the usual orientation of the reference coordinate axes?

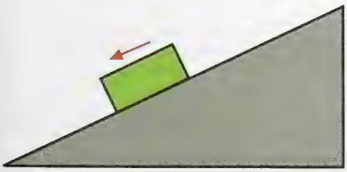
SC 10. If the angle between the slope and the horizontal is 40°, figure out the angle for the following:

a. the weight vector ($\vec{F}_g$) and the perpendicular component ($\vec{F}_{g\perp}$)

b. the weight vector ($\vec{F}_g$) and the parallel component ($\vec{F}_{g\parallel}$)

Check your work with the answer in the appendix.

Go to your Physics 20 Multimedia DVD, and re-open the "Free-Body Drawer" simulation, if it is not still open. Select "project" from the drop-down menu titled "Projects" at the top of the applet. Choose the "Image" button (Image). Select the lower-left image of an inclined plane, and click OK. You should have the following image on your screen.



mass accelerating down a rough plane

As you did with other images, draw the free-body diagram vectors. Make the weight vector green, the normal vector blue, and the force of friction vector red. Check your work by clicking the "Check" button (Check) and selecting "FBD" (FBD).

Self-Check

SC 11. On a copy of your FBDs of the mass accelerating down a rough plane, put in the components of the weight vector that are parallel and perpendicular to the slope using a different shade of green for each.

SC 12. For the object to accelerate down the slope, which component vector must have a greater magnitude than the force of friction? Why?

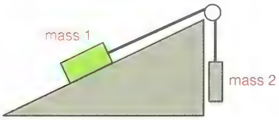
SC 13. Draw the coordinate axis diagram for the slope situation pictured.

Check your work with the answer in the appendix.

Module 3: Lesson 4 Assignment

Remember to submit the answer to TR 3 to your teacher as part of your Lesson 4 Assignment in your Module 3 Assignment Booklet.

TR 3. Load the image of the second incline, shown below, using the "Image" button (**Image**).



mass 1 accelerating
up a smooth plane

Complete the table by doing the following:

- Identify and list all of the forces in the system. (Assume the "smooth plane" is a frictionless surface.)
- Draw correctly labelled free-body diagrams for both mass 1 and mass 2. Add the relevant components of the weight ($\vec{F}_{g\parallel}$ and $\vec{F}_{g\perp}$).
- On your free-body diagrams, draw convenient coordinate systems and assign vector directions for the situation of both mass 1 and mass 2.
- Derive the relevant net force equations for the FBD for the situations along the slope (mass 1) and also the situation in the vertical direction (mass 2).

Read

Free-body diagrams are essential for solving friction problems involving objects on an incline. To see why, read "Example 3.18" on page 186 and "Example 3.20" on pages 188 and 189 of your textbook. Look for the information you will need to answer the following question.

Self-Check

SC 14. To calculate the force of friction on a slope when the coefficient of friction is given, the normal force is needed.

a. How do you calculate the normal force?
b. If the sled in "Example 3.20" had a mass of 65 kg, what would the normal force be?

Check your work with the answer in the appendix.

Reflect and Connect

A 4.22×10^3-kg ambulance is on its way to the scene of a motor vehicle collision. The engine produces an applied force of 2.11×10^4 N. The force of friction (force opposing the motion) is 1.50×10^3 N. Use this scenario as a way to think about free-body analysis in a real-world setting. Be sure to consider all of the forces acting on the ambulance so you can determine the net force and observed acceleration of the vehicle. Remember how important it is to select and use appropriate coordinate axes and define the direction of the acceleration based on them.

Place your finished work in your Physics 20 course folder. Your teacher may require you to submit this question for review.

Discuss

Construct a flow chart that summarizes the process for constructing a free-body diagram and generating an equation for the net force acting along the *x*-and *y*-axes. At a minimum, include and define the following terms within your flow chart:

- friction
- weight
- applied force
- normal force
- coordinate axis
- net force
- observed acceleration
- vector magnitude and direction

Go to the discussion area ready to discuss your flow chart with other students, and modify it based on the discussion. After the discussion, you will submit your modified flow chart to your teacher for review.

Reflect on the Big Picture

Each of the Reflect on the Big Picture sections in this module will ask you to consider the movement of people or goods. To help you reflect on your learning experience in this lesson, complete at least one of the following activities:

- Brainstorm to create a list of situations where people move from place to place. Create a presentation with your situations on it. Mark each situation with a free-body diagram.

- Are the net forces acting on a dump truck the same when the truck is empty and when the truck is full of sand? Using free-body diagrams, explain the similarities or differences that exist when an empty dump truck turns a corner compared to a dump truck that is full of sand.

Store your completed reflection in your Physics 20 course folder.

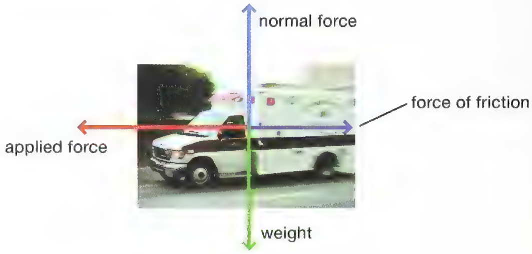
Module 3: Lesson 4 Assignment

Make sure you have completed all of the questions for the Lesson 4 Assignment. Check with your teacher about whether you should submit your assignment now or wait until all of the Module 3 assignments have been completed. You should also submit your completed work from Discuss and Reflect and Connect to your teacher for review.

Lesson Summary

As you worked through this lesson, you should have developed answers to these questions.

- How is the motion of an object affected by the forces applied to it?
- How do unbalanced forces affect the motion of an object?
- How do free-body diagrams, vector analyses, and Newton's second law help solve moving-object problems?



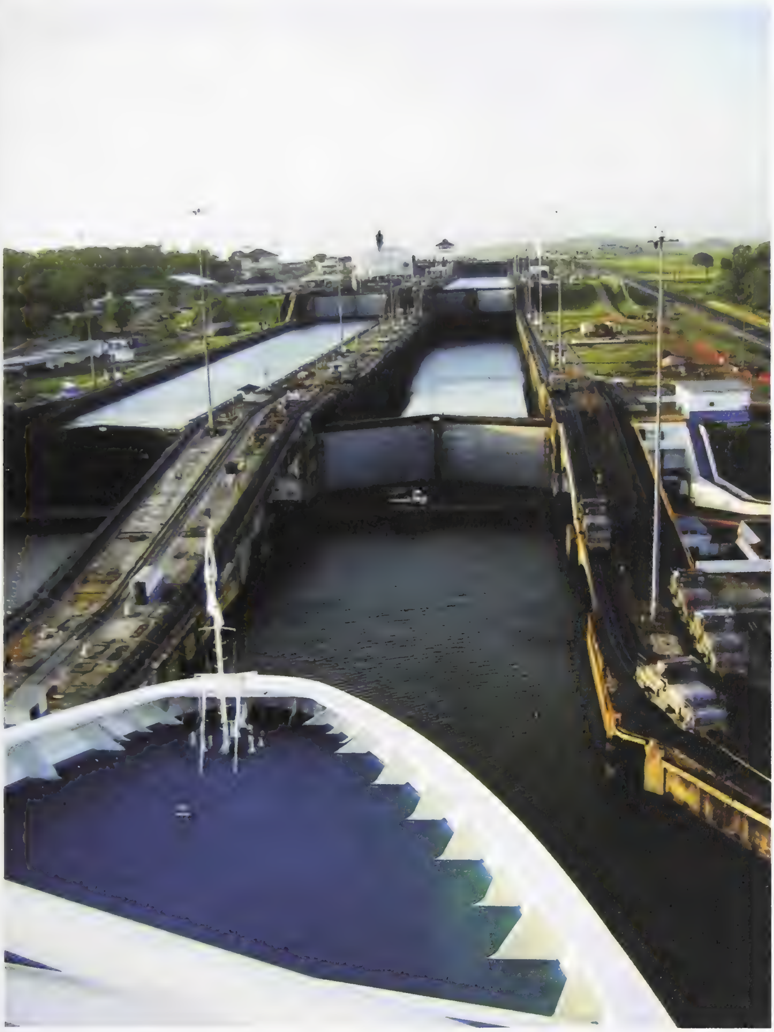
© Aaron Kohr/shutterstock

A free-body diagram is an indispensable tool used in the analysis of forces and the application of Newton's laws. It is a representation of all the forces acting on a body or system. If a system consists of more than one body, then a free-body diagram must be constructed for each body.

Free-body diagrams and Newton's second law are used to generate equations that predict the magnitude and direction of the net force and observed acceleration of an object along a defined coordinate axis.

Lesson 5—Solving Net Force Problems

Get Focused



© Jim Lipschutz /shutterstock

This is a photo taken from one of the upper decks of a cruise ship that is about to enter the Panama Canal. This canal is a technological solution for moving a ship from the Atlantic Ocean to the Pacific Ocean, through the Central American country of Panama. The canal works by passing boats through a series of locks, which raise and lower the boats through a vertical distance of 26 m between the oceans.

Constructing this canal was one of the most difficult engineering projects ever undertaken. It opened in 1914, after an estimated 27 500 workers died during the construction. By 2002, nearly 800 000 ships had used the canal. In 2005 alone, 200 million tonnes of cargo passed through it.

Using the canal is not cheap: In 2006, the container ship *Maersk Dellys* paid $249 165 for passage.

In contrast, an American adventurer by the name of Richard Halliburton paid $0.36 to swim the canal in 1928. The average cost to pass through the canal is around $54 000.

Large ships do not use their engines to pass through the canal. In the photograph, notice the rail tracks on either side of the canal passageway. Tug locomotives are along these tracks. Using a cable, a ship is attached to a tug locomotive on each side of the canal. The locomotives pull the ship straight through each of the locks in the canal. Two locomotives, one on each side, are used to do this. If the tug locomotives are positioned on either side of the boat, how can they pull the ship straight forward through the canal? How do they avoid having the tug locomotives pull the ship into the side of the canal?

In this lesson and the associated labs, you will learn to apply Newton's second law and free-body diagram analysis to solve linear (one-dimensional) and non-linear (two-dimensional) net-force problems.

This lesson is where you bring Newton's laws and free-body diagrams together.

As you work through this lesson, keep this question in mind:

- How do free-body diagrams, vector analyses, and Newton's second law help solve moving-object problems?

Module 3: Lesson 5 Assignments

In this lesson you will complete the Lesson 5 Assignment in the Module 3 Assignment Booklet.

- Try This—TR 1, TR 2, TR 3, TR 4, and TR 5
- Lab—LAB 1, LAB 2, LAB 3, LAB 4, LAB 5, and LAB 6

You must decide what to do with the questions that are not marked by the teacher.

Remember that these questions provide you with the practice and feedback that you need to successfully complete this course. You should respond to all the questions and place those answers in your course folder.

Explore

According to Newton's second law, if an unbalanced force is applied to an object, it will accelerate in the direction of the unbalanced force. The fact that an unbalanced force can act on an object implies that there can be multiple forces acting on a single object all at the same time.

The unbalanced force is often called the *net force* because it is the vector sum of all the forces acting on an object.	$\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots$	(1)
You will recall that net force can be found by multiplying mass times acceleration.	$\vec{F}_{\text{net}} = m\vec{a}$	(2)
Combining equations (1) and (2) gives equation (3). This equation can be used to determine the acceleration of an object with multiple (unbalanced) forces acting on it.	$m\vec{a} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots$ $\vec{a} = \dfrac{\vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots}{m}$	(3)

To correctly apply equation (3), you need to generate a free-body diagram and add the unbalanced forces as vectors in one or two dimensions. To do this, you need to recall two concepts:

- how to draw a free-body diagram
- how to add vectors in one and two dimensions

The net-force problems in this lesson will be limited to one-dimension and two-dimensions, and they will fall into four general categories:

- linear (one dimensional)
- at right angles (two dimensional)
- at various angles (two dimensional)
- on an incline

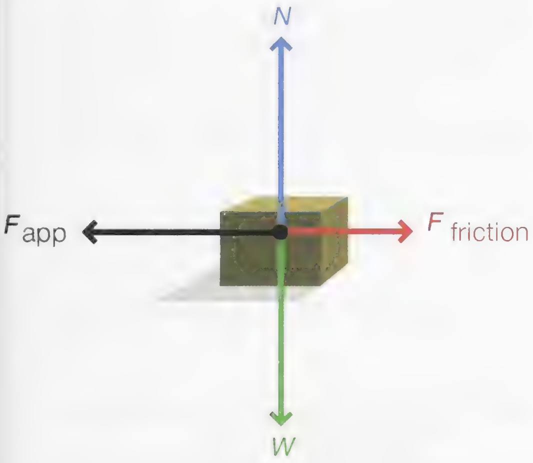
Following are examples of each type of problem. Use these examples to help you complete the practice problems on the following worksheet.

Example Problem 1: Linear (One Dimensional)

A 5.00-kg box rests on a rough surface where the coefficient of kinetic friction is 0.150. A 35.0-N force [left] is applied to the box, and it begins to accelerate. What is the acceleration of the box just after it begins to move?

Analysis

The normal force is equal in magnitude to the weight (N = W); therefore, there is no unbalanced vertical force, making this a one-dimensional problem. Let the positive direction be toward the right.



$$\vec{F}_{\text{net}} = \vec{F}_{\text{app}} + \vec{F}_{\text{friction}}$$

$$m\vec{a} = \vec{F}_{\text{app}} + m\vec{g}\mu_s$$

$$\vec{a} = \frac{\vec{F}_{\text{app}} + m\vec{g}\mu_s}{m}$$

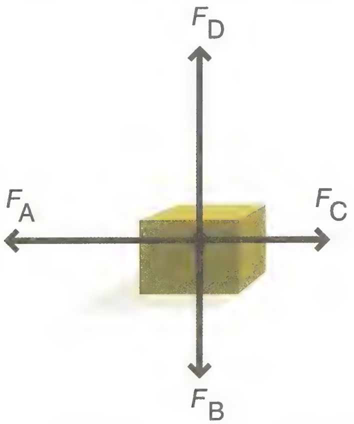
$$\vec{a} \doteq \frac{(-35.0\text{ N}) + (5.00\text{ kg})(9.81\text{ m/s}^2)(0.150)}{5.00\text{ kg}}$$

$$\vec{a} = -5.53\text{ m/s}^2 \text{ correct to 3 significant digits}$$

This indicates that the box will accelerate in the same direction as the applied force with a magnitude (correct to 3 significant digits) of 5.53 m/s_2. The acceleration of the box just as it begins to move is 5.53 m/s^2 [left].

Example Problem 2: At Right Angles (Two Dimensional)

A 10.0-kg box rests on a smooth, frictionless surface. Four ropes are attached to the box, one on each side.



- Rope A applies a 65.0-N force towards the west.
- Rope B applies a 30.0-N force towards the south.
- Rope C applies a 20.0-N force towards the east.
- Rope D applies a 70.0-N force towards the north.

Calculate the acceleration of the box.

Analysis

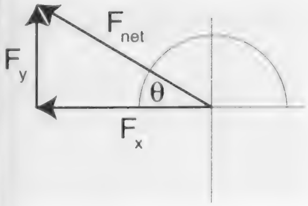
Let the east direction be the positive *x* direction and north be the positive *y* direction. Adding the east-west forces gives the following:

$$\vec{F}_x = \vec{F}_A + \vec{F}_C$$
$$\vec{F}_x = (-65.0\ \text{N}) + (+20.0\ \text{N})$$
$$\vec{F}_x = -45.0\ \text{N}$$

Adding the north-south forces gives the following:

$$\vec{F}_y = \vec{F}_D + \vec{F}_B$$
$$\vec{F}_y = (+70.0\ \text{N}) + (-30.0\ \text{N})$$
$$\vec{F}_y = +40.0\ \text{N}$$

Add the total east-west force to the total north-south force as vectors.



$$\left(\vec{F}_{net}\right)^2 = \left(\vec{F}_x\right)^2 + \left(\vec{F}_y\right)^2$$

$$\left|m\vec{a}\right| = \sqrt{\left(\vec{F}_x\right)^2 + \left(\vec{F}_y\right)^2}$$

$$\left|\vec{a}\right| = \frac{\sqrt{\left(\vec{F}_x\right)^2 + \left(\vec{F}_y\right)^2}}{m}$$

$$\left|\vec{a}\right| \doteq \frac{\sqrt{(-45.0\text{ N})^2 + (+40.0\text{ N})^2}}{10.0\text{ kg}}$$

$$\left|\vec{a}\right| = 6.02\text{ m/s}^2 \text{ correct to 3 significant digits}$$

$$\theta = \tan^{-1}\left(\frac{\text{opposite}}{\text{adjacent}}\right)$$

$$\theta = \tan^{-1}\left(\frac{+40.0\text{ N}}{-45.0\text{ N}}\right)$$

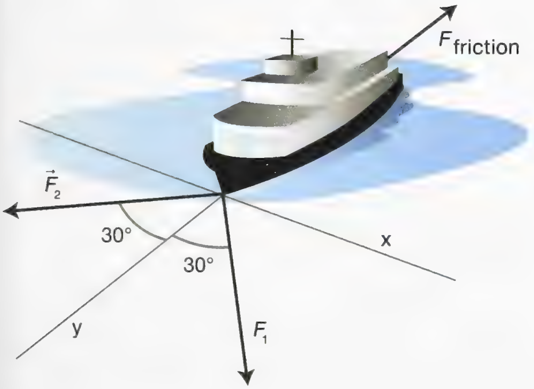
$$\theta = 41.6^\circ \text{ correct to 3 significant digits}$$

Therefore, the net force and acceleration have the following polar positive direction:

$180° – 41.6°= 138.4°$

$\vec{a} = 6.02\text{ m/s}^2$ at 138° (polar positive), correct to 3 significant digits.

Example Problem 3: At Various Angles (Two Dimensional)

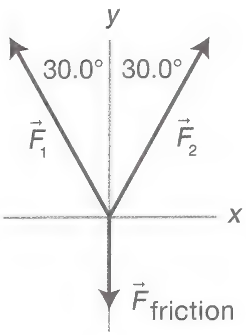


Two tug boats are pulling a larger ship, as illustrated.

- $\vec{F}_1 = 3.80 \times 10^5$ N
- $\vec{F}_2 = 4.00 \times 10^5$ N
- $\vec{F}_{friction} = 1.00 \times 10^5$ N
- mass = 5.00×10^6 kg

An *x-y* coordinate system has been assigned (as illustrated). Calculate the acceleration of the larger ship.

Orient the diagram so that friction acts in the negative y direction.

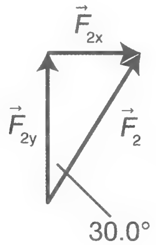


Analysis

Step 1: Resolve $\vec{F}_1$ and $\vec{F}_2$ into x and y components.

$\vec{F}_2$ components

Recall that $F_2 = 4.00 \times 10^5$ N



$$\cos(\theta) = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\text{adjacent} = \cos(\theta) \times \text{hypotenuse}$$

$$\left|\vec{F}_{2y}\right| = \cos(30.0°)(4.00 \times 10^5 \text{ N})$$

$$\left|\vec{F}_{2y}\right| \doteq 346410.1615 \text{ N}$$

$$\sin(\theta) = \frac{\text{opposite}}{\text{hypotenuse}}$$

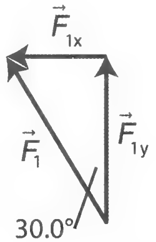
$$\text{opposite} = \sin(\theta) \times \text{hypotenuse}$$

$$\left|\vec{F}_{2x}\right| = \sin(30.0°)(4.00 \times 10^5 \text{ N})$$

$$\left|\vec{F}_{2x}\right| \doteq 200000 \text{ N}$$

$\vec{F}_1$ components

Recall that $F_1 = 3.80 \times 10^5$ N



$$\cos(\theta) = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\text{adjacent} = \cos(\theta) \times \text{hypotenuse}$$

$$\left|\vec{F}_{1y}\right| = \cos(30.0°)(3.80 \times 10^5 \text{ N})$$

$$\left|\vec{F}_{1y}\right| \doteq 329089.6534 \text{ N}$$

$$\sin(\theta) = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\text{opposite} = \sin(\theta) \times \text{hypotenuse}$$

$$\left|\vec{F}_{1x}\right| = \sin(30.0°)(3.80 \times 10^5 \text{ N})$$

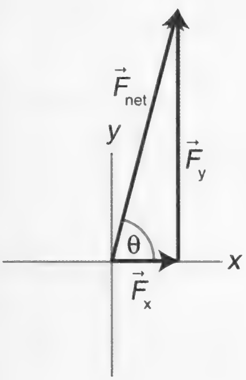
$$\left|\vec{F}_{1x}\right| \doteq 190000 \text{ N}$$

Step 2: Determine the total x and y forces.

Add all of the x forces.
$$\vec{F}_x = \vec{F}_{1x} + \vec{F}_{2x}$$
$$\vec{F}_x \doteq (-190000\text{ N}) + (+200000\text{ N})$$
$$\vec{F}_x \doteq +10000$$

Add all of the y forces.
$$\vec{F}_y = \vec{F}_{1y} + \vec{F}_{2y} + \vec{F}_{\text{friction}}$$
$$\vec{F}_y \doteq (329089.6534\text{ N}) + (346410.1615\text{ N}) + \left(-1.00\times10^5\text{ N}\right)$$
$$\vec{F}_y \doteq 575499.8149\text{ N}$$

Step 3: Add the x and y components as vectors.



$$\left(\vec{F}_{\text{net}}\right)^2 = \left(\vec{F}_x\right)^2 + \left(\vec{F}_y\right)^2$$
$$m\left|\vec{a}\right| = \sqrt{\left(\vec{F}_x\right)^2 + \left(\vec{F}_y\right)^2}$$
$$\left|\vec{a}\right| = \frac{\sqrt{\left(\vec{F}_x\right)^2 + \left(\vec{F}_y\right)^2}}{m}$$
$$\left|\vec{a}\right| = \frac{\sqrt{(10\,000\text{ N})^2 + (575\,499.8149\text{ N})^2}}{5.00\times10^6\text{ kg}}$$
$$\left|\vec{a}\right| \doteq 0.115\,117\,337\,9\text{ m/s}^2$$
$$\left|\vec{a}\right| = 0.115\text{ m/s}^2 \text{ correct to 3 significant digits}$$

$$\theta = \tan^{-1}\left(\frac{\text{opposite}}{\text{adjacent}}\right)$$
$$\theta = \tan^{-1}\left(\frac{575\,499.8149\text{ N}}{10\,000\text{ N}}\right)$$
$$\theta \doteq 89.004\,517\,25^\circ$$
$$\theta = 89.0^\circ \text{ correct to 3 significant digits}$$

Therefore, the net force and acceleration have the following polar positive direction: 89.0°

$\vec{a} = 0.115\text{ m/s}^2$ at 89.0° (polar positive), correct to 3 significant digits

Example Problem 4: On an Incline

A cross-country cyclist encounters an incline into a river valley that is marked as a 6% grade on the road sign. This corresponds to an angle of 3.4° down from horizontal. If the cyclist and the loaded bike have a combined mass of 95 kg, and the force of friction is initially 40 N, what will be the initial acceleration of the cyclist down the hill?

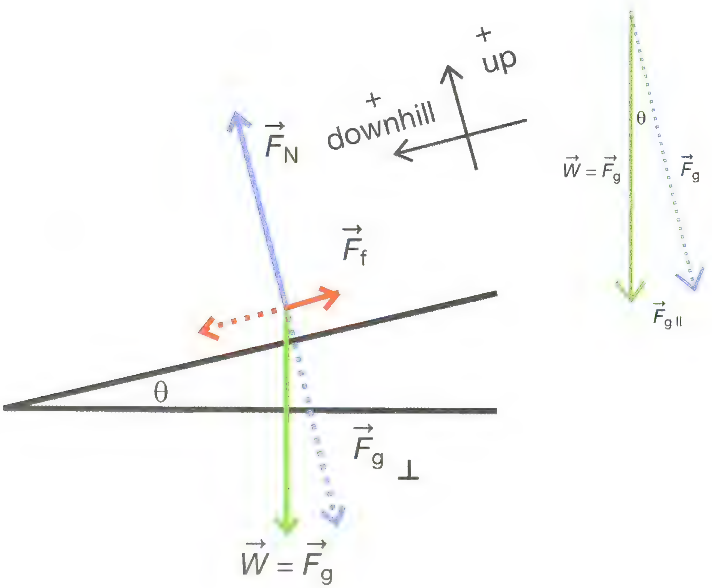
Given

$m = 95$ kg $F_f = 40$ N $\theta = 3.4°$

Required

the acceleration of the cyclist down the hill ($\vec{a}$)

Analysis and Solution



The normal force ($\vec{F}_N$) is equal in magnitude but opposite in direction to $\vec{F}_{g\perp}$, so there is no acceleration in the up-down direction. These forces can be ignored.

The magnitude of the $\vec{F}_{g\parallel}$ can be calculated using the formula $\vec{F}_{g\parallel} = \vec{F}_g \sin\theta$, as can be seen by resolving the weight into its components in the tip-to-tail vector diagram shown above.

In the parallel direction,

$$\vec{F}_{\text{net}} = \vec{F}_{g\parallel} + \vec{F}_{f}$$

Working only with magnitudes,

$$F_{\text{net}} = F_{g\parallel} - F_{f}$$
$$F_{\text{net}} = F_{g}\sin\theta - F_{f}$$
$$F_{\text{net}} = mg\sin\theta - F_{f}$$

$$\begin{aligned} a &= \frac{F_{\text{net}}}{m} \\ &= \frac{mg\ \sin\theta - F_{f}}{m} \\ &= \frac{(95\ \text{kg})(9.81\ \text{m/s}^2)(\sin 3.4^\circ) - (20\ \text{N})}{95\ \text{kg}} \\ &= 0.37\ \text{m/s}^2 \end{aligned}$$

Paraphrase

The cyclist will initially accelerate at $0.37\ \text{m/s}^2$ [downhill].

Read

To get a perspective that will help in solving the following assignment questions, read "Applying Newton's Second Law to Horizontal Motion" on pages 149 to 151 of your textbook.

Module 3: Lesson 5 Assignment

Remember to submit the answers to TR 1, TR 2, TR 3, and TR 4 to your teacher as part of your Lesson 5 Assignment in your Module 3 Assignment Booklet.

Try This

TR 1. A crate of bananas with a mass of 25.0 kg is dragged across a level floor by an applied force of +150 N [E] against a frictional force of 50.0 N [W]. What is the observed acceleration of the crate?

TR 2. A milk carton with a mass of 2.00 kg is pulled across a table with a horizontal force of 3.00 N. If the coefficient of friction is 0.110, what is the acceleration of the milk carton?

TR 3. A box of cereal is pushed with an applied force of 2.4 N [W] across a table. If the cereal box has a mass of 2.5 kg and the box accelerates at 0.41 m/s^2 [W], what is the force of friction? What is the coefficient of friction for the table top?

TR 4. A 5.0-kg toolbox is pulled west across a concrete floor with a rope. The rope makes an angle of 45.0° with the floor. A force of 85.0 N is exerted on the rope, and the force of friction is 15.0 N parallel to the floor. Calculate the acceleration of the box.

In the previous lesson you drew free-body diagrams for several objects that were connected, either by touching or joined by a cord. In the following lab you will extend that understanding and calculate the accelerations and forces involved in these interactions.

Lesson 5 Lab: Fletcher's Trolley

Introduction

This lab simulates the motion of two masses connected by a string and pulley. You can explore the potential, kinetic, and total energy of the system. It also uses free-body analysis to determine the acceleration of the system, the tension in the string, and the weight acting on each block.

You can learn more about the simulation and how to use it by reading Show Me found at the top of the simulation screen.

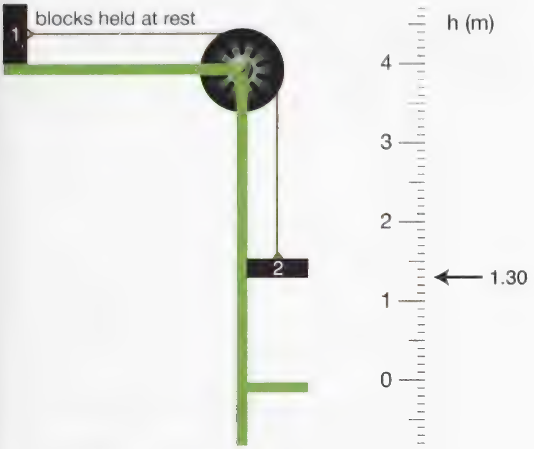
Problem

How do you determine the acceleration of two connected bodies using Fletcher's Trolley?

Go to **www.learnalberta.ca**. You may be required to input a username and password. Contact your teacher for this information. Enter the search terms "Fletcher's Trolley" in the search bar. Open the Fletcher's Trolley simulation; then continue with the procedure.

Procedure

Imagine two blocks connected by a rope. Now, imagine that one of the blocks is hung over the edge of a table via a pulley. What would happen to the blocks if they were free to move? Would both blocks begin to accelerate? If so, would they accelerate at the same rate if the rope does not stretch? The apparatus used to answer such questions is known as Fletcher's Trolley.



The simulation will be used to observe the acceleration of two blocks on Fletcher's Trolley.

- Click the "Reset" button ( ).
- The lower edge of block 2 will be at elevation $h = 1.30$ m, and the yellow platform will be at $h = 0$ m.
- The masses of the blocks will be

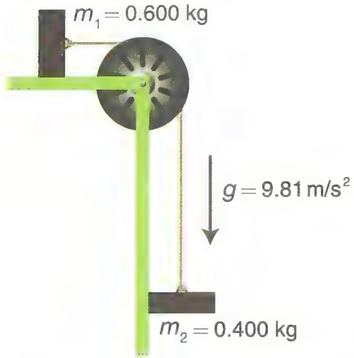
  $m_1 = 600$ g
  $m_2 = 400$ g

- The pulley's mass will be zero. These mass values will be assumed in all of the following explanations, except where otherwise noted.
- Click on block 1, and drag it until block 2 is at elevation $h = 3.00$ m. Maximize the applet window ( ) if you are not able to drag block 1 far enough to the left.
- Click "Play" ( ), and observe the motion of the blocks. You can click the "Data" button ( ) to see the values displayed and use "Rewind" and "Play" to see the action again. Describe the motion of the blocks using the terms *speed*, *time*, and *acceleration*.

Observations and Analysis

An engineer who wants to design a system with a specific acceleration must be able to calculate the acceleration from the parameters defining the system. In the case of Fletcher's Trolley, these parameters are the masses of the two blocks and the magnitude of the acceleration due to gravity (g). Given the parameters illustrated here, how can you calculate the magnitude of the acceleration (a) of the two blocks?

You know that gravity is providing acceleration on one of the blocks and that the two blocks have to accelerate at the same rate because they are attached by a string that can not stretch. Applying Newton's second law to the two blocks separately will give two equations for two unknowns. The two unknowns are acceleration and tension.



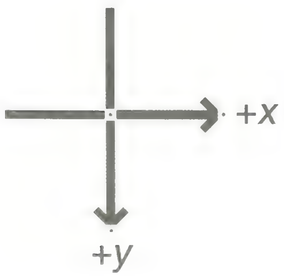
- Both blocks have accelerations of the same magnitude *(a)* because the string is assumed not to stretch.
- The pulley and the string are thought of as having no mass, and the pulley is considered to be frictionless. Therefore, the tension (T) in the string is equal along the entire length of the string. Suppose you denote the magnitude of the force on block 1 as T_1 and the force on block 2 as T_2. Then you can state that T, T_1, and T_2 are equal.

$$T = T_1 = T_2$$

The acceleration of the blocks can be determined by setting up two basic equations and solving them in terms of acceleration.

Setting Up the Basic Equations

Step 1: Define the directions. The coordinate axes (directions) are defined in the simulation.



- horizontal: positive to the right
- vertical: positive downward

Step 2: View the free-body diagrams (FBD) by clicking the "FBD" button (FBD) that will illustrate the forces acting on each block. The FBD for block 2 is at the far right of the window.

FBD 1	Equation for Block 1	FBD 2	Equation for Block 2
 N_1 and W_1 cancel	Applying Newton's second law ($F_{net} = ma$) to block 1 yields the following equation: $F_{net} = T_1$ $m_1a = T_1$ (1)		Applying Newton's second law ($F_{net} = ma$) to block 2 yields the following equation: $F_{net} = (+W_2) + (-T_2)$ $m_2a = m_2g - T_2$ (2)

Module 3: Lesson 5 Assignment

Remember to submit the answer to LAB 1 to your teacher as part of your Lesson 5 Assignment in your Module 3 Assignment Booklet.

LAB 1. Equations (1) and (2) are the fundamental equations governing the motion of the system. Each of these equations can be used independently to determine the tension in the string.

a. Using equation (1), calculate the tension in the string if $m_1 = 0.600$ kg and $a = 3.92$ m/s^2. Show your work. Verify your answer using the applet.

b. Using equation (2), calculate the tension in the string if $m_2 = 0.400$ kg and $a = 3.92$ m/s^2. Show your work. Verify your answer using the applet. Your answer should be identical to LAB 1.a.

Step 3: Combine equations (1) and (2) to generate an equation to solve for the acceleration of the system.

Express equation (2) in terms of T_2. Use the fact that $T_2 = T_1$ to equate equations (1) and (2).

$$(2)\ m_2a = m_2g - T_2$$
$$T_2 = m_2g - m_2a$$

$$(1)\ T_1 = m_1a$$
$$m_1a = m_2g - m_2a$$
$$m_1a + m_2a = m_2g$$

$$a(m_1 + m_2) = m_2g$$

Manipulating the equation in terms of acceleration gives

$$a = \frac{m_2g}{m_1 + m_2}$$

Solving for the acceleration gives

$$a = \frac{(0.400 \text{ kg})(9.81 \text{ m/s}^2)}{0.600 \text{ kg} + 0.400 \text{ kg}}$$

$$a \doteq 3.924 \text{ m/s}^2$$

$$a = 3.92 \text{ m/s}^2 \text{ correct to 3 significant digits}$$

Verify that this is the value for the acceleration as displayed by the applet.

Self-Check

SC 1. Given the following masses, calculate the acceleration of the system.

$m_1 = 0.600$ kg
$m_2 = 0.500$ kg

Show your work. Verify your answer on the applet by adjusting the mass values to match those given. The mass values on the applet are controlled by the mass slider. You can make fine mass adjustments by clicking in the slot to the left or right of the slider.

Check your work with the answer in the appendix.

Module 3: Lesson 5 Assignment

Remember to submit the answer to LAB 2 to your teacher as part of your Lesson 5 Assignment in your Module 3 Assignment Booklet.

LAB 2. Given the following masses, calculate the acceleration of the system.

$m_1 = 0.600$ kg
$m_2 = 0.800$ kg

Verify your answer on the applet by adjusting the mass values to match those given. The mass values on the applet are controlled by the mass slider. Show your work.

How can you calculate the tension present in the string when the blocks are moving?

The tension is not measured as easily as the acceleration. You would have to insert a strain gauge into the string, which would have a mass. This would have an effect on the conditions in the system, including the tension. Therefore, it is particularly important that you know how to calculate the tension. For example, an engineer who needs to design a system like Fletcher's Trolley will want to know how strong to make the string so that it will not break under the tension that it will need to sustain.

If the acceleration has already been measured or calculated, the easiest way to find the tension is to substitute the value for acceleration *(a)* into either equation (1) or (2).

Using Equation 1

$T_1 = m_1 a$
$T_1 \doteq (0.600 \text{ kg})(3.924 \text{ m/s}^2)$
$T_1 \doteq 2.3544 \text{ kg} \bullet \text{m/s}^2$
$T_1 = 2.35 \text{ kg} \bullet \text{m/s}^2$ correct to 3 significant digits

Using Equation 2

$T_2 = m_2 g - m_2 a$
$T_2 \doteq (0.400 \text{ kg})(9.81 \text{ m/s}^2) - (0.400 \text{ kg})(3.924 \text{ m/s}^2)$
$T_2 \doteq 2.3544 \text{ kg} \bullet \text{m/s}^2$
$T_2 = 2.35 \text{ kg} \bullet \text{m/s}^2$ correct to 3 significant digits

The simulation displays a value of 2.4 N, which is consistent with these calculations.

Module 3: Lesson 5 Assignment

Remember to submit the answer to LAB 3 to your teacher as part of your Lesson 5 Assignment in your Module 3 Assignment Booklet.

LAB 3. Notice that the tension value of 2.35 N is *less* than the weight of block 2. The weight of block 2 is calculated by $W_2 = m_2 g = (0.400 \text{ kg})\ (9.81 \text{ m/s}^2) = 3.92 \text{ N}$

What would the acceleration of the system be if the tension were equal to the weight of block 2? Explain your answer. (**Hint:** Study the free-body diagram of block 2 to answer this.)

Conclusion

The acceleration of two connected bodies on Fletcher's Trolley can be determined by setting up two basic equations and solving them in terms of acceleration.

Read

Read pages 153 to 157 of your textbook.

Self-Check

SC 2.

Go to page 158 of your textbook and complete question 9(a) of "3.3 Check and Reflect."

Check your work with the answer in the appendix.

If you have ridden an elevator in a tall building, you have no doubt felt an apparent change in your weight. You feel slightly heavier as the elevator starts upward and a little lighter as it slows to a stop at an upper floor. When you ride back down, you feel lighter when the elevator starts down and slightly heavier as it slows and stops at a lower floor. Can Newton's laws explain this? Investigate how the motion of an elevator relates to Newton's laws in the following lab.

Lesson 5 Lab: Elevator Lab

Introduction

This lab simulates the motion of an elevator. It helps you apply free-body analysis and Newton's second law to determine the relationship between apparent weight, normal force, and actual weight.

You can learn more about the simulation and how to use it by reading Show Me found at the top of the simulation screen.

Problem

How do you determine the acceleration of an elevator?

Background Information

Before starting the lab, check your understanding for the precise meaning of these terms.

- *Weight* is the gravitational force exerted by Earth on an object. Note that weight is based on Newton's second law ($\vec{F} = m\vec{a}$). Expressed as an equation, it is

  $$\vec{W} = m\vec{g}$$

Quantity	Symbol	SI Unit
weight	$\vec{W}$	N
mass	m	kg
acceleration due to gravity	$\vec{g}$	m/s^2
* The acceleration due to gravity at Earth's surface is approximately $-9.81\ m/s^2$.		

- *Normal force* is the force exerted by a surface on another body. For example, when you stand on the floor, the floor exerts an upward force on you. The normal force is always perpendicular to the surface.

- *Apparent weight* is the name given to the force that you exert on another body—perhaps a weigh scale. For example, if you stand on a bathroom scale, you exert a downward force on the scale (your apparent weight). This is equal in magnitude to the normal force that the scale exerts on you. Therefore, the magnitude of the apparent weight equals the magnitude of the normal force.

Module 3: Lesson 5 Assignment

Remember to submit the answer to LAB 4 to your teacher as part of your Lesson 5 Assignment in your Module 3 Assignment Booklet.

LAB 4. Using the definitions above, complete the following calculations and explanations.

a. Calculate the weight of a 60.0-kg person on Earth's surface.

b. Suppose you jumped onto your bathroom scale. Would the scale initially indicate a high weight and then settle down to your actual weight? (**Note:** The initial weight would be your apparent weight at the moment you landed on the scale.)

c. Your apparent weight can be greater than your actual weight. Is this **true** or **false**? Explain.

Procedure

Go to **www.learnalberta.ca**. You may be required to input a username and password. Contact your teacher for this information. Enter the search term “Elevator” in the search bar. Open the Elevator simulation; then continue with the procedure.

- On the simulation, adjust the passenger “Mass” slider () and observe how the weight and normal force vectors respond. Pay close attention to what happens to the normal force as the weight of the passenger changes.

- Use the applet to simulate a variety of up-and-down elevator trips at different accelerations for a 60.0-kg passenger. You can change the mass by moving the slider or double-clicking on the slider and entering the number you want. Carefully observe the magnitude of both the normal force and passenger weight throughout each trip.

Observations and Analysis

Self-Check

SC 3. Answer the following questions based on your observation of the passenger weight and normal force on any elevator trip.

a. Is the passenger's weight constant throughout a typical elevator trip regardless of any acceleration?
b. Is the normal force constant throughout a typical elevator trip?
c. Essentially, an elevator causes motion by adjusting only the normal force. Is this **true** or **false**? Explain.

Check your work with the answer in the appendix.

Set up the following parameters on the elevator applet:

- Double-click the mass slider, and enter the mass of the occupant as 60.0 kg.
- Double-click the acceleration slider, and set the acceleration at 4.0 m/s^2.
- Press the "Up" button ( ) to start the elevator.

The elevator will accelerate, coast, and then come to a stop. This represents a typical elevator trip. Observe carefully what happens to the weight (W) and normal force (N) vectors that are drawn on the simulation during each phase of the trip. Once the elevator has stopped, you may wish to reset the elevator and observe the motion again.

Self-Check

SC 4. Use the terms *greater than*, *equal to*, or *less than* to compare the size of the normal force when the elevator is at rest to the size of the normal force as the elevator

a. accelerates upward
b. coasts
c. slows down

Check your work with the answer in the appendix.

Module 3: Lesson 5 Assignment

Remember to submit the answer to LAB 5 to your teacher as part of your Lesson 5 Assignment in your Module 3 Assignment Booklet.

LAB 5. The apparent weight of the passenger equals the magnitude of the normal force acting on the passenger. Use the terms *greater than*, *equal to*, or *less than* to compare the passenger's weight when the elevator is at rest to the apparent weight when the elevator

a. accelerates upward
b. coasts
c. slows down

Self-Check

SC 5. Based on your observations and experience riding in an elevator, which force, weight or apparent weight, do you feel when the elevator

a. accelerates upward
b. coasts
c. slows down

SC 6. Complete the table by drawing the free-body diagrams in each phase of the elevator trip. Indicate the relative magnitude (size) of the normal force and the weight on each diagram.

a. accelerating upward (+) (speeding up)	b. coasting/resting (constant speed)	c. accelerating downward (–) (slowing down)
		

SC 7. The net force acting on the occupant is the sum of all force acting on the occupant. This is described by

$$\vec{F}_{\text{net}} = \vec{N} + \vec{W}$$

a. Rewrite the equation using Newton's second law, where

- "$m\vec{a}$" is substituted for "$\vec{F}_{\text{net}}$"
- "$m\vec{g}$" is substituted for "$\vec{W}$"

(______) = ($\vec{N}$) + (______) (2)

b. Manipulate the equation in SC 7.a. in terms of the normal force ($\vec{N}$).

$\vec{N}$ = (______) – (______) (3)

Check your work with the answer in the appendix.

The equation $\vec{N} = (m\vec{a}) - (m\vec{g})$ can be used to determine the apparent weight of a passenger when the acceleration ($\vec{a}$) of the elevator is known.

For example, what is the apparent weight of a 55.0-kg person on an elevator that is accelerating upward at 3.00 m/s^2?

$$\vec{N} = m\vec{a} - m\vec{g}$$
$$\vec{N} = (55.0\ \text{kg})\left(+3.00\ \text{m/s}^2\right) - (55.0\ \text{kg})\left(-9.81\ \text{m/s}^2\right)$$
$$\vec{N} \doteq 704.55\ \text{N}$$
$$\vec{N} = 704\ \text{N, correct to 3 significant digits}$$

Self-Check

SC 8. An elevator ride consists of three distinct phases characterized by the acceleration of the elevator itself: accelerating upward, coasting/resting, and accelerating downward. Complete the following chart. Calculate the normal force using equation $\vec{N} = (m\vec{a}) - (m\vec{g})$ and the values for m = 60.0 kg and $\vec{a}$ = +4.0 m/s^2 for each phase of the elevator trip. The value of $\vec{g}$ is –9.81 m/s^2. You will need to set the mass of the passenger and the acceleration ($\vec{a}$) of the elevator in the applet. Note that the direction and magnitude of the acceleration will be different in each phase of the trip and that they are indicated in the following table. Verify your answers on the simulation using the normal force value from the scale reading shown in the upper left corner of the applet.

Accelerating Upward (+) (speeding up)	$(\vec{a} = +4.0\ \text{m/s}^2)$ $\vec{N} =$
Coasting/Resting (constant speed)	$(\vec{a} = +0.0\ \text{m/s}^2)$ $\vec{N} =$
Accelerating Downward (–) (slowing down)	$(\vec{a} = -4.0\ \text{m/s}^2)$ $\vec{N} =$

SC 9. Consider the three distinct phases of an elevator ride:

- accelerating upward (speeding up)
- coasting/resting (constant speed)
- accelerating downward (slowing down)

For two of the phases of the ride, scale readings indicate apparent weight. For the remaining phase, the reading is actual weight.

a. In which two phases are the scale readings apparent weights?
b. For which phase does the scale reading represent the "heavy" sensation you would feel on this elevator trip?
c. For which phase does the scale reading represent the "light" sensation you would feel on this elevator trip?

Check your work with the answer in the appendix.

Read

To reinforce what you have learned in the elevator lab so far and to prepare for your next assignment question, read "Applying Newton's Second Law to Vertical Motion" on pages 151 to 153 of your textbook.

Module 3: Lesson 5 Assignment

Remember to submit the answer to LAB 6 to your teacher as part of your Lesson 5 Assignment in your Module 3 Assignment Booklet.

LAB 6. Use the simulation for assistance in answering the following questions.

a. Calculate the apparent weight of an 80.0-kg person riding in an elevator that is accelerating upward at a rate of 5.00 m/s^2.

b. Use a free-body diagram to explain what happens to the apparent weight of a person if the elevator begins to "free fall" (accelerating downward at 9.81 m/s^2).

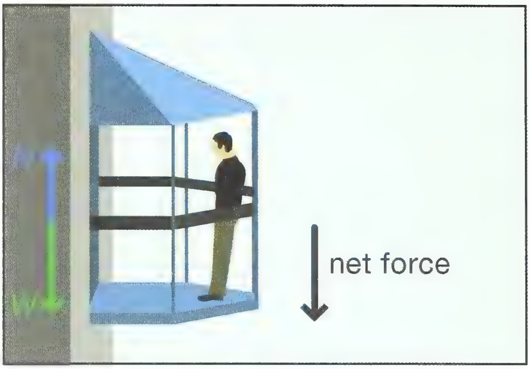
c. You are in an elevator that is accelerating upward at 6.00 m/s^2. If your apparent weight is 800 N, what is your mass?

d. A passenger on an elevator experiences an apparent weight of 500 N while accelerating downward. If the mass of the passenger is 70.0 kg, at what rate is the passenger accelerating?

e. While travelling down between floors at a constant speed, a passenger has a weight of 800 N. During the acceleration to stop the elevator, the passenger experiences an apparent weight of 1000 N. Calculate the acceleration of the elevator.

Conclusion

The acceleration of an elevator can be determined using free-body analysis and Newton's second law.



$\vec{F}_{net} = \vec{N} + \vec{W}$

The observed acceleration (a) is related to the net force by Newton's second law.

$\vec{F}_{net} = m\vec{a}$

N is the normal force, which is equal in magnitude to the passenger's apparent weight.

W is the actual weight of the passenger, produced by the effect of the gravity acting on a mass: $W = mg$

Read

In the elevator lab, you were dealing with a hypothetical frictionless surface. In the next assignment question you will have kinetic friction on a slope. Read "Kinetic Friction" on pages 176 to 179 of your textbook. Compare the example there with "Example 3.18" on page 186 and "Example 3.20" on pages 188 and 189 of your textbook. Do you see a similar pattern?

Module 3: Lesson 5 Assignment

Remember to submit the answer to TR 5 to your teacher as part of your Lesson 5 Assignment in your Module 3 Assignment Booklet.

Try This

TR 5. In "Example 3.16" on page 179 of your textbook and in the text titled "Example Problem 4: On an Incline" that you studied in the first part of this lesson, the $\vec{F}_{net\perp}$ did not enter into the calculations. However, the $\vec{F}_{net\perp}$ was part of the calculations in "Example 3.18" and "Example 3.20."

a. Why was $\vec{F}_{net\perp}$ needed in the last two examples but not the first two?

b. What formula was used to calculate $\vec{F}_{net\perp}$?

Reflect and Connect

Work out how two canal tug locomotives can pull a ship straight forward even when the locomotives are connected to the side of the ship via cables. Your explanation should include

- a free-body diagram showing all the forces
- an explanation of the types of forces involved
- a component analysis showing how the total force along each axis is determined
- a vector diagram showing the total force along each axis

Discuss

When you have worked out your explanation for the Reflect and Connect section, go to the discussion area to share it and discuss other possibilities. You may wish to modify your explanation based on the discussion. After the discussion, place your explanation in your Physics 20 course folder.

Reflect on the Big Picture

Each of the Reflect on the Big Picture sections in this module will ask you to consider the movement of people or goods. To help you reflect on your learning experience in this lesson and module, complete at least one of the following activities:

- Have you or someone you know needed to have a vehicle towed out of a snowbank? Contrast the forces involved in towing someone out of a snowbank.

- Prepare a short report examining the forces on a cargo ship being moved through the Panama Canal. An Internet search may interest you. Choose one of the following presentation formats:

    - written report
    - PowerPoint presentation
    - short audio or podcast report
    - short video report

Store your completed reflection in your Physics 20 course folder.

Module 3: Lesson 5 Assignment

Make sure you have completed all of the questions for the Lesson 5 Assignment. Submit your Module 3 Assignment Booklet to your teacher.

Choose one item that you added to your Physics 20 course folder in Module 3, and share it with your teacher.

Lesson Summary

As you worked through this lesson, you should have developed answers to this question:

- How do free-body diagrams, vector analyses, and Newton’s second law help solve moving-object problems?

According to Newton's second law, if an unbalanced force is applied to an object, it will accelerate in the direction of the unbalanced force. The unbalanced force can be a net force, which is the vector sum of all the forces acting on an object. Using the net force, the magnitude and direction of the acceleration can be determined in a variety of situations.

For one- and two-dimensional forces acting on a single body:

- Draw a free-body diagram.
- Using components (if necessary), determine the total net force acting along each axis.
- Draw a vector diagram using the total force acting along each axis.
- Add the total force of each axis as vectors.
- State the net force and acceleration.

For connected bodies:

- Define the directions using a coordinate axes.
- Construct a free-body diagram for each body.
- Generate an equation for the net force and acceleration of each body.
- Combine the equations, and manipulate to solve for the acceleration and/or tension in the system.

Effects of Force on Velocity

Module Summary

Isaac Newton is one of the major figures in the history of dynamics. You've seen his name throughout the module, Effects of Force on Velocity. Most of the work you've completed revolved around Newton's laws of motion, which are stated here in a modern translation:

- **Newton's First Law: The Law of Inertia:** A body at rest remains at rest. A body in motion continues to move in a straight line with a constant speed (e.g., constant velocity) unless an external, unbalanced force acts on it.
- **Newton's Second Law:** $\vec{F} = m\vec{a}$: The rate of change of velocity of an object is proportional to, and in the same direction as, the unbalanced force acting on it.
- **Newton's Third Law:** $\vec{F}_{action} = -\vec{F}_{reaction}$: For every action force, there exists a reaction force that is equal in magnitude but opposite in direction.

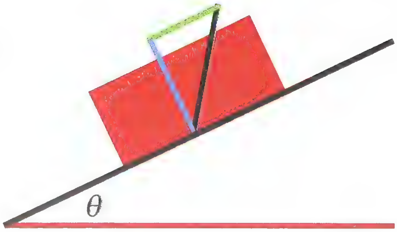
As you were working in this module, you were asked to keep the following questions in your mind. Did you see how your studies helped you answer them?

- How is the motion of an object affected by forces applied to it?
- How do unbalanced forces affect the motion of an object?
- How do Newton's laws help explain why motion occurs?
- How do you find a reaction force?
- How does friction affect moving objects?
- How does friction affect making an object move?
- How do free-body diagrams, vector analyses, and Newton's second law help solve moving-object problems?

Newton's first and second laws explain the vector motion of an object and can be applied to understand and solve problems related to moving objects, like a child climbing to the top of a slide. Newton's third law explains how two bodies interact with an action-reaction force pair.

Since there are many forces that can act on a single object, a way to keep track of them all is needed. You've used free-body diagrams as a way to keep track of multiple forces acting on a single object. They are used along with Newton's second law to find equations that explain what will happen next.

When a child sits at the top of a slide, what forces are being applied that you know about but that the child isn't aware of? One is the normal force supporting the child's body where it is in contact with the slide. On a flat, horizontal surface, this is just the child's weight, which from Newton's second law is $\vec{W} = m\vec{g}$.



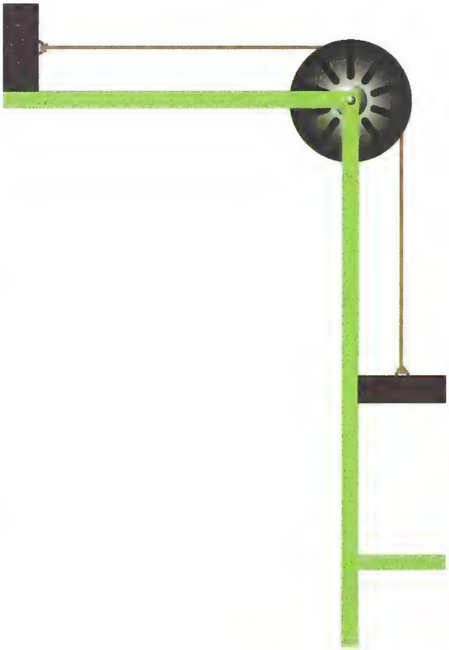
On sloped surfaces, you have to find the portion of the weight that acts perpendicular to the surface. In the accompanying diagram, the normal force corresponds to the blue line in the triangle. You can find it from the weight (the black line) using the equation $\vec{F}_N = m(\cos(\theta))\vec{g}$.

Another force the child might not think of is friction. This force opposes the relative motion of two surfaces that are in contact. Friction is a tricky concept—it seems to decrease when an object finally starts moving. That's why you studied both moving (kinetic) and stationary (static) friction. The following equations relate the normal force and the frictional forces.

$$\vec{F}_{\text{kinetic}} = \mu_k \vec{F}_{\text{N}}$$
$$\vec{F}_{\text{static}} = \mu_s \vec{F}_{\text{N}}$$

You've also used Newton's second law to find the acceleration an unbalanced force gives an object. Often, you had to calculate a net force, which is the vector sum of all the forces acting on an object, to find the acceleration. Do you think a youngster pushing herself forward to start down a slide thinks of all of this?

You've probably used the following processes when you were asked to work with forces acting on objects.



For one- and two-dimensional forces acting on a single body:
- Make a free-body diagram.
- Find the total net force acting along each axis using components, if necessary.
- Draw a vector diagram using the total force acting along each axis.
- Find the total force by adding the force on each axis as vectors.
- State the net force and acceleration.

For connected objects:
- Define the directions using a coordinate axis.
- Construct a free-body diagram for each body.
- Generate an equation for the net force and acceleration of each body.
- Combine the equations.
- Manipulate the equations to solve for the acceleration and/or tension in the system.

With these tools available to you, you will be beginning to study another of Newton's contributions to physics, namely the study of gravity.

Module Assessment

The assessment for Module 3 consists of five (5) assignments:
- Module 3: Lesson 1 Assignment
- Module 3: Lesson 2 Assignment
- Module 3: Lesson 3 Assignment
- Module 3: Lesson 4 Assignment
- Module 3: Lesson 5 Assignment

Glossary

coefficient of kinetic friction: ratio of friction force to normal force once two objects in contact stop moving as one object

coefficient of static friction: ratio of the maximum friction force to normal force while two objects in contact move as one object

force: a push or a pull, the cause of any change in the motion of an object

free-body diagram: a drawing of a system with forces acting on it

friction: the resistance to motion between two surfaces in contact

inertia: a property of matter that causes matter to resist changes in speed or direction

kinetic friction: the type of friction that an object is subject to after it is in motion

net force: the sum of the forces acting on an object (see *unbalanced force*)

normal force: the perpendicular force that a surface exerts on an object with which it is in contact

static friction: the friction between two objects that are in contact but are not moving

unbalanced force: a net push or pull in one direction

weight: a measure of the force of gravity on an object

Self-Check Answer

Lesson 1

SC 1. The tendency of objects to resist any change in their velocity is called *inertia*.

SC 2. Objects in motion usually come to rest despite their inertia because the unbalanced forces of friction and air resistance continually decrease the speed of the objects. In other words, friction and air resistance give objects a negative acceleration.

SC 3. Object B will have one-third the acceleration of object A.

Lesson 2

SC 1. Complete the following sentence by filling in the blank. In Newton's third law, the two forces not only act in different directions, they also act on different **objects**.

SC 2. Other answers are possible, but two situations where action-reaction forces act on objects that are not in contact include the following:

- Earth's gravity pulling on an object, and the object pulling on Earth
- a magnet pulling on an iron object, and the iron object pulling on the magnet

SC 3.

a. Three forces exerted on box B in "Example 3.12" are the force of gravity, a force from box A, and a force from box C. (Another force is the normal force holding it up.)

b. Three forces exerted on box B in "Example 3.13" are the force of gravity, a force from box A, and the force of friction. (Another force is the normal force holding it up.)

SC 4.

a. The action-reaction pair that provides thrust in propeller aircraft is the propeller pushing the air backwards and the air pushing the propeller forward.

b. The action-reaction pair that provides thrust in rockets is the push of the exhaust gas backwards by the rocket engine and the push on the rocket engine by the exhaust gas.

SC 5.

8. (a)

Given

$m_X = 10$ kg $m_Y = 5.0$ kg $\vec{F}_{\text{app}} = 36$ N [right]

Required

the action-reaction forces of the blocks on each other ($\vec{F}_{\text{X on Y}}$ and $\vec{F}_{\text{Y on X}}$)

Analysis and Solution

Only the horizontal forces need to be considered. Let the direction to the right be positive. Calculate the acceleration of the two-block system. Then calculate the force necessary to accelerate block Y, which will be $\vec{F}_{\text{X on Y}}$.

$$\begin{aligned}\vec{a} &= \frac{\vec{F}_{\text{net}}}{m} \\ &= \frac{36\ \text{N}}{(10\ \text{kg} + 5.0\ \text{kg})} \\ &= 2.4\ \text{m/s}^2\end{aligned}$$

$$\begin{aligned}\vec{F}_{\text{X on Y}} &= m\vec{a} \\ &= (5.0\ \text{kg})(2.4\ \text{m/s}^2) \\ &= 12\ \text{N}\end{aligned}$$

The positive value indicates the force is to the right. By Newton's third law, the force of block Y on block X will be equal in magnitude but in the opposite direction or left.

Paraphrase

The force of block X on block Y is 12 N [right], and the force of block Y on block X is 12 N [left].

8.(b)

Given

$m_X = 10$ kg $\quad m_Y = 5.0$ kg $\quad \vec{F}_{\text{app}} = 36$ N [right] $\quad F_{\text{f on X}} = 8.0$ N
$F_{\text{f on Y}} = 4.0$ N

Required

the action-reaction forces of the blocks on each other ($\vec{F}_{\text{X on Y}}$ and $\vec{F}_{\text{Y on X}}$)

Analysis and Solution

Only the horizontal forces need to be considered. The direction of the forces of friction will be left because that is opposite to the direction of travel. Calculate the acceleration of the two-block system. Then calculate the net force that accelerates block Y.

$$\vec{a} = \frac{\vec{F}_{\text{net}}}{m}$$
$$= \frac{(36\text{ N} - 8.0\text{ N} - 4.0\text{ N})}{(10\text{ kg} + 5.0\text{ kg})}$$
$$= 1.6\text{ m/s}^2$$

$$\vec{F}_{\text{net}_Y} = m\vec{a}$$
$$= (5.0\text{ kg})(1.6\text{ m/s}^2)$$
$$= 8.0\text{ N}$$

The positive value indicates the force is to the right. However, block X must exert an extra 4.0 N to overcome the force of friction on block Y. Therefore, the force of block X on block Y will be (8.0 N + 4.0 N) or 12 N. By Newton's third law, the force of block Y on block X will be equal in magnitude but in the opposite direction or left.

Paraphrase

The force of block X on block Y is 12 N [right], and the force of block Y on block X is 12 N [left].

SC 6. This is not an application of Newton's third law because both of the forces are acting on the *same* object—the block. In any application of Newton's third law, the action and reaction force must act on *different* objects.

Lesson 3

SC 1.

a. Rubber on dry asphalt has the second highest coefficient of static friction.
b. The curling stone on ice has the lowest coefficient of kinetic friction.

SC 2.

Given

$\vec{F}_g = W = 2350\text{ N [down]}$ $\mu_k = 0.7$

Required

the force of kinetic friction ($F_{f_{\text{kinetic}}}$)

Analysis and Solution

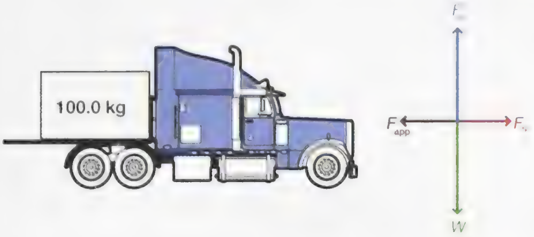
The normal force will be equal in magnitude but opposite in direction to the weight of the bike. The force of kinetic friction will be opposite to the direction of motion.

$$F_{f_{\text{kinetic}}} = \mu_k F_N$$
$$= (0.7)(2350\text{ N})$$
$$= 1645\text{ N}$$
$$= 2\text{ kN to 1 significant digit}$$

Paraphrase

The force of kinetic friction is 2 kN [opposite to the direction of motion].

SC 3. The direction of the truck and the force arrows may be reversed.



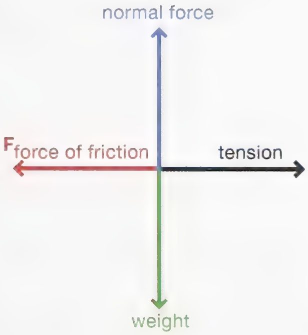
If the box does not slide on the truck bed, then the maximum acceleration is determined by the maximum static frictional force.

$$
\begin{aligned}
F_{\mathrm{f\ static}} &= \mu_s F_N \\
&\le \mu_s mg \\
&\le (0.30)(100.0\ \text{kg})(9.81\ \text{m/s}^2) \\
&\le 294.3\ \text{N}
\end{aligned}
\qquad
\begin{aligned}
F &= ma \\
a &= \frac{F}{m} \\
&= \frac{294.3\ \text{N}}{100.0\ \text{kg}} \\
&= 2.9\ \text{m/s}
\end{aligned}
$$

The maximum acceleration of the truck without the box sliding is 2.9 m/s^2.

Lesson 4

SC 1.

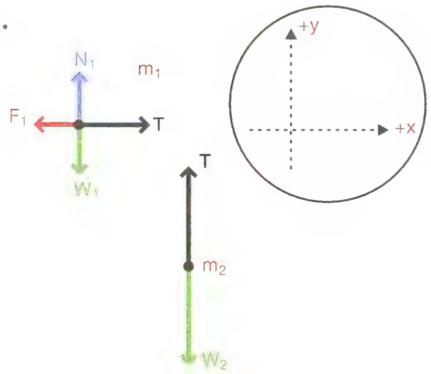


No, not all of the forces are balanced. Although the normal force and weight are indeed balanced, the tension force is greater in magnitude than the force of friction; therefore, the block accelerates in the direction of the larger force.

SC 2.

Here are the FBDs shown for the masses connected by a rope and pulley without mass. Note that a set of coordinate axes has also been drawn. You must draw it yourself—the simulation will not assign or draw a coordinate axis. Choose the "Draw New Vectors" mode (◉ **Draw New Vectors**)and draw and label the coordinate axes.

SC 3.



The coordinate axis defines up and right as positive directions and down and left as negative directions.

SC 4.

a. $\vec{N}_1$ positive

b. $\vec{F}_f$ negative

c. $\vec{W}_1$ negative

d. $\vec{W}_2$ negative

e. $\vec{T}$ positive

SC 5.

Analysis and Solution

We will assume the vertical forces are balanced and only consider the horizontal forces, choosing the forward forces as positive.

$$\vec{F}_{\text{net}} = \vec{F}_{\text{dog A}} + \vec{F}_{\text{dog B}} + \vec{F}_{\text{friction}} + \vec{F}_{\text{driver}}$$
$$F_{\text{net}} = F_{\text{dog A}} + F_{\text{dog B}} + F_{\text{friction}} + F_{\text{driver}}$$
$$= 200\text{ N} + 150\text{ N} + (-60\text{ N}) + (-100\text{ N})$$
$$= 190\text{ N}$$
$$\vec{F}_{\text{net}} = 190\text{ N [forward]}$$

Paraphrase

The net force on the sled is 190 N [forward].

SC 6. After a free-body diagram for the object was drawn, the next step was to resolve all forces into x and y components.

SC 7.

Given

$\vec{F}_A = 65.0\text{ N }[30.0°]$ $\vec{F}_B = 70.0\text{ N }[300°]$

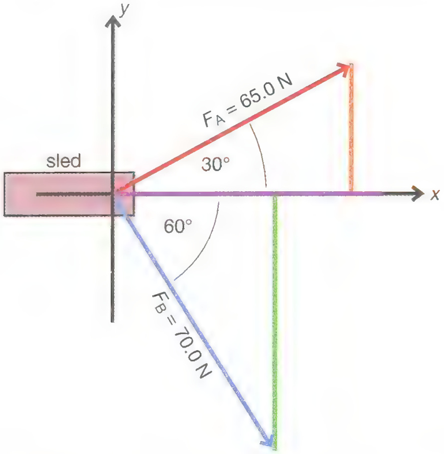
Required

the net force on the sled ($\vec{F}_{\text{net}}$)

Analysis and Solution

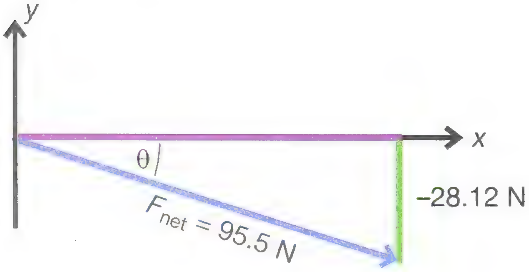
Draw a free-body diagram of the situation. An angle of 300° is the same angle as –60°.

Resolve all forces into *x* and *y* components. Find the sum of the *x* and *y* components separately.



Vector	*x* component	*y* component
$\vec{F}_A$	(65.0 N)(cos 30.0°)	(65.0 N)(sin 30.0°)
$\vec{F}_B$	(70.0 N)(cos 60°)	–(70.0 N)(sin 60°)
$\vec{F}_{net}$	91.29 N	–28.12 N

Calculate the magnitude of the net force using the theorem of Pythagoras and the direction of the net force using the tangent function.



$$\tan\ \theta = \frac{\text{opposite}}{\text{adjacent}}$$

$$\tan\ \theta = \frac{28.12\text{ N}}{91.29\text{ N}}$$

$$\theta = \tan^{-1}\left(\frac{28.12\text{ N}}{91.29\text{ N}}\right)$$

$$= 17.1^\circ$$

$$F_{net} = \sqrt{\left(F_x\right)^2 + \left(F_y\right)^2}$$

$$F_{net} = \sqrt{(91.29\text{ N})^2 + (28.12\text{ N})^2}$$

$$F_{net} = 95.5\text{ N}$$

The angle measured in polar coordinates is (360° – 17.1°) or 343°.

Paraphrase

The net force on the sled is 95.5 N [343°]

SC 8. The perpendicular component ($\vec{F}_{g\perp}$) is equal in magnitude but opposite in direction to the normal force.

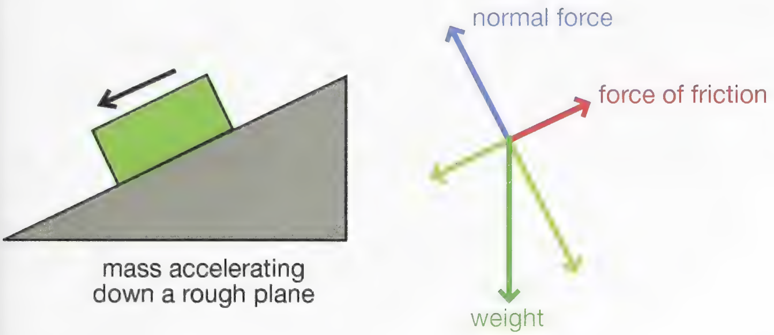
SC 9. In free-body diagrams of an object on an incline, one reference coordinate axis is usually oriented parallel to the slope, with the uphill direction positive (unless the object is accelerating down the slope). The other reference coordinate axis is usually oriented perpendicular to the slope with the upward direction positive.

SC 10.

a. The angle between the weight vector ($\vec{F}_g$) and the perpendicular component ($\vec{F}_{g\perp}$) will be 40°.

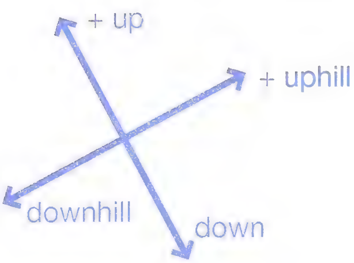
b. The angle between the weight vector ($\vec{F}_g$) and the parallel component ($\vec{F}_{g\parallel}$) will be (90° – 40°) or 50°.

SC 11.



SC 12. For the object to accelerate down the slope, the component of the weight vector parallel to the slope $\vec{F}_{g\parallel}$ must have a greater magnitude than the force of friction. According to Newton's second law, for acceleration to occur, there must be an unbalanced force in the direction of the acceleration. Since the force of friction and $\vec{F}_{g\parallel}$ are collinear, and the force of friction is opposite to the direction of motion, acceleration occurs down the slope only when $\vec{F}_{g\parallel}$ is greater, so the net force is directed down the slope.

SC 13. It also would be perfectly acceptable to have chosen the downhill direction as positive and the uphill direction negative in the diagram below, because the acceleration is downhill.



SC 14.

a. The normal force and the component of the weight perpendicular to the slope ($\vec{F}_{g\perp}$) are related. They are equal in magnitude but opposite in direction. The formula used is $\vec{F}_N = mg\cos\theta$.

b.
$$\vec{F}_N = mg\cos\theta$$
$$\vec{F}_N = (65\text{ kg})(9.81\text{ m/s}^2)(\cos\ 25.0°)$$
$$\vec{F}_N = 5.8\times10^2\text{ N}$$

If the sled in "Example 3.20" had a mass of 65 kg, the normal force would be 5.8×10^2 N.

Lesson 5

SC 1.

$$a = \frac{m_2 g}{(m_1 + m_2)}$$
$$a = \frac{(0.500\text{ kg})(9.81\text{ m/s}^2)}{(0.600\text{ kg} + 0.500\text{ kg})}$$
$$a = 4.46\text{ m/s}^2$$

The simulation uses the rounded value 9.8 m/s^2 for g and therefore calculates the acceleration to be 4.45 m/s^2.

SC 2.

Given

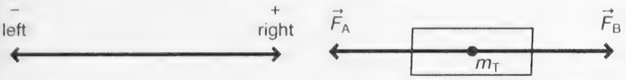
$m_A = 4.0$ kg, where m_A is the mass of the oak block
$m_B = 2.0$ kg, where m_B is the mass hanging down

Required

$a = ?$

Analysis and Solution

Equivalent system



$\vec{F}_A$ is equal to the friction force on m_T.

$\vec{F}_B$ is equal to the gravitational force on m_T.

$\vec{F}_{net} = \vec{F}_A + \vec{F}_B$

$$
\begin{aligned}
F_A &= -11.8\ \text{N} \\
F_B &= m_B g \\
&= (2.0\ \text{kg})(9.81\ \text{m/s}^2) \\
&= 19.62\ \text{N}
\end{aligned}
$$

$$
\begin{aligned}
F_{net} &= -11.8\ \text{N} + 19.62 \\
&= +7.82\ \text{N} \\
a &= \frac{F_{net}}{m_T} \\
&= \frac{+7.82\ \text{N}}{6.0\ \text{kg}} \\
&= +1.30\ \text{m/s}^2 \\
\vec{a} &= 1.30\ \text{m/s}^2\ [\text{right}]
\end{aligned}
$$

Paraphrase

The acceleration of the system is 1.30 m/s^2 to the right.

SC 3.

a. Yes, the weight vector is only a product of the passenger's mass and the acceleration due to gravity.

b. No, the normal force changes based on the acceleration of the elevator.

c. True. By adjusting the normal force while the weight remains constant, the elevator is able to create a net force acting either up or down, which causes the accelerated motion.

SC 4.

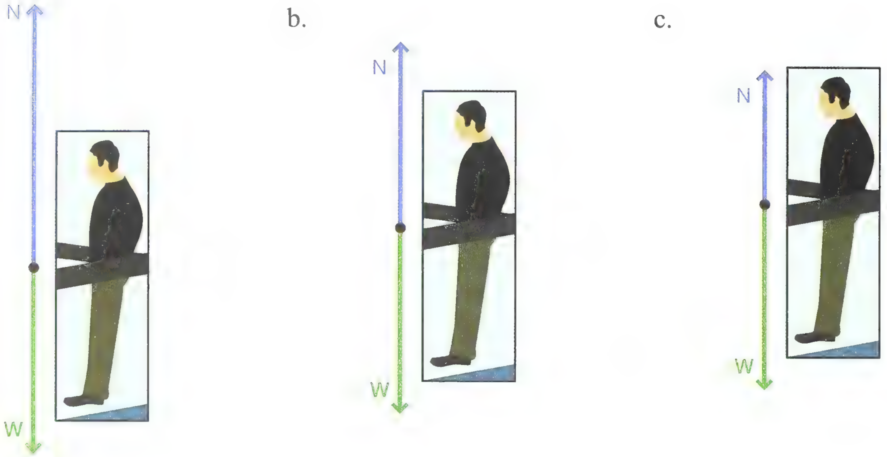
a. $F_{\text{N accelerating}}$ is **greater than** $F_{\text{N rest}}$
b. $F_{\text{N coasting}}$ is **equal to** $F_{\text{N rest}}$
c. $F_{\text{N slowing}}$ is **less than** $F_{\text{N rest}}$

SC 5.

a. apparent weight
b. weight
c. apparent weight

SC 6.

a. b. c.



SC 7.

a. $(m\vec{a}) = (\vec{N}) + (m\vec{g})$

b. $\vec{N} = (m\vec{a}) - (m\vec{g})$

SC 8.

Accelerating Upward (+) (speeding up)	$\vec{N} = m\vec{a} - m\vec{g}$ $\vec{N} = (60.0\text{ kg}) + \left(+4.0\text{ m/s}^2\right) - (60.0\text{ kg})\left(-9.81\text{ m/s}^2\right)$ $\vec{N} = +829\text{ N}$
Coasting/Resting (constant speed)	$\vec{N} = m\vec{a} - m\vec{g}$ $\vec{N} = (60.0\text{ kg}) + \left(0.0\text{ m/s}^2\right) - (60.0\text{ kg})\left(-9.81\text{ m/s}^2\right)$ $\vec{N} = +589\text{ N}$
Accelerating Downward (–) (slowing down)	$\vec{N} = m\vec{a} - m\vec{g}$ $\vec{N} = (60.0\text{ kg}) + \left(-4.0\text{ m/s}^2\right) - (60.0\text{ kg})\left(-9.81\text{ m/s}^2\right)$ $\vec{N} = +349\text{ N}$

SC 9.

a. accelerating upward and accelerating downward
b. accelerating upward
c. accelerating downward